PROCEEDINGS

OF THE

ROYAL SOCIETY OF EDINBURGH.

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Ninety-Sixth Session.

Monday, 16th December 1878.

Professor KELLAND, President, in the Chair.

The following Communications were read :—

I. On the Action of Light on the Iris. By William Ackroyd, F.I.C., &c. Communicated by Professor M'Kendrick.

Sect. I. It is well known that the movements of the iris are due to the stimulus of light, but I am not aware that any experiments have been hitherto made to determine the approximate quantity of that agent necessary to bring about this involuntary action. The usual way of observation precludes refined experimenting, it being customary to watch the iris of another person or animal whilst under the influence of varying amounts of light, or one's own iris by means of a mirror. Three methods will be described here, and I believe that one at least may afford a means of getting new data on this and other points.

Sect. II. The first and second methods depend upon the following facts :—That, if a divergent bundle of rays emanate from a small surface or hole, very near to the eye (say about 30 mm. off), this surface or hole is the apex of a cone of light whose base is the pupil; that every movement of the iris affects the area of this base, which

appears as a circular luminous field; and finally, that I find these alterations of area, so easily seen, may be taken as indications of the movements of the iris.

The third method is equally simple. The lachrymal fluid on the surface of the cornea affects the image of any light source, such as a lamp or star, and by refraction causes the appearance of rays to emanate therefrom.

It is obvious that the length of these rays must be regulated by the iris, this organ being nearer to the retina, hence when the pupil contracts the rays ought to shorten, and when the pupil expands the rays ought to lengthen out. Such I find to be the case.

Sect. III. *The First or Reflection Method.*—The following is the simplest form of the experiment I have been able to devise. Burnish the head of an ordinary brass pin, and place the pin up to head in a black hat. Now, with one eye shut and your back to the light, bring this pin-head near to the other eye so that the light may be reflected into it from the convex surface of the pin-head.

One sees a circular luminous field, with projecting hairs at the bottom which belong to the top eyelid.* Globules of the lachrymal fluid also appear at each wink.

Expt. 1. Shade the light from the observing eye for a few seconds, then let the light fall on it again. Notice the alteration in area of the field of view. The field contracts, then expands slightly, and oscillates until the iris is adjusted for the amount of light falling into the eye.

Expt. 2. Observe the pin-head with the right eye for some moments, the left eye being closed. Open the left eye. The iris of the right eye is seen to move markedly, the pupil contracting. *Here the iris of the right eye is moved by the light entering the left one.*

Expt. 3. With everything as in Expt. 2, have both eyes closed and only open the right or observing eye. There is contraction of the pupil, but apparently no more marked than in Expt. 2.

* A simple method is here suggested for demonstrating to one's self the inverting action of the crystalline lens. With everything as here described, take a needle and bring it across the field of view *close* to the eyelids. *If it move downwards, it appears to move upwards; if it be moved upwards, it appears to come downwards.*

Sect. IV. *The Second or Transmission Method.*—Prick a pin-hole in tinfoil. Shut one eye and bring the hole within 12 mm. off the open eye.

Expts. 1, 2, and 3 may readily be repeated by this method.

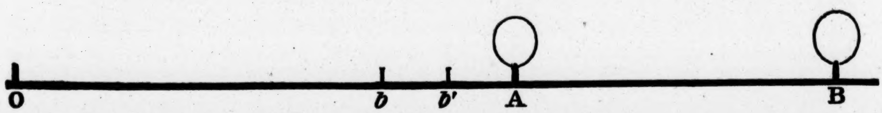
Expt. 4. Place green glass before the aperture, and notice the size of the field, then withdraw the glass suddenly. The pupil contracts. Red glass gave the same result.

Sect. V. *The Third or Refraction Method.*—The following example will make perfectly clear the way of working here:—I am looking at a star, with the moon at full, a little to one side. From the star proceed the rays mentioned at the close of Sect. II. Upon turning towards the moon, but still keeping my attention concentrated on the star, the rays of the latter appear to retreat into it; and upon turning from the light of the moon, the rays emanate from the star again.

Expt. 5. This is typical of about seventy other experiments I have made. The night is starless. An isolated gas lamp, with no houses near or any other sources of light, appears when seen from a distance with the usual rays emanating from it. I walk towards it slowly. At 300 yards no alteration has taken place in the rays; they appear fixed. The distance is slowly decreased, but not until I am at a distance of 16 yards do the rays perceptibly shorten; in other words, the light from this one gas lamp is incompetent to effect a movement of my iris until I am within 16 yards of it. The shortening of the rays is now rapid, for at 10 yards distance the light appears to be without them.

Expt. 6. In the preceding experiment there is a possibility that the rays may be shortened to some extent by the increase in size of the image on the surface of the cornea as we near the light. In the present experiment this objection is to some extent removed. Two gas lamps were chosen, 50 yards apart, and whilst walking towards the nearest my attention was kept exclusively on the rays emanating from the farthest one. As the first lamp is approached, the effect of its light on the iris is visible in the alteration of length of rays proceeding from the far one. Thus in the fig. the two lamps are A and B, and the observer stationed at O sees rays emanating from both. A is the lamp whose influence on the iris is to be tested, and B is the lamplight used as a tester. Proceeding from O

towards B, a point b is reached at which the lamp rays of B begin to shorten, *i.e.*, the light of A affects the iris. Getting nearer still



to A, a point b' is reached, where the distant light B appears to have lost its rays.

The average of a dozen experiments gave as the value of bA... 14 yards, and as the value of b'A... 8 yards. Squaring these numbers, it appears that about one-third of the light competent to contract the pupil very markedly is sufficient to start its movement.

At present, I abstain from comment, as I am continuing these experiments.

2. On a New Variety of Ocular Spectrum. By John Aitken.

If we look for a short time at any object, and afterwards turn the eye in another direction, we see a spectral image of the form of the object first looked at.

Again, if after we have looked at any coloured object we turn the eye in another direction, we see a spectral image of a colour complimentary to that first looked at.

In addition to these spectral forms and colours, I find there is another and distinct kind of ocular spectrum, which we may call a motion spectrum. It is seen when we look first at a body in motion and afterwards direct the eye towards an object at rest. The object at rest, when seen under these conditions, seems to be in motion, and the direction of its apparent motion is the opposite of that of the moving body first looked at.

I first observed this motion spectrum when looking at the surface of a river where it was flowing rapidly, the eye being afterwards directed to a gravel bank. The first effect seemed to be an indistinctness of vision, but, on carefully repeating the experiment, I was much astonished to observe that, after looking steadily at the stream and then at the gravel bank, a narrow spectral stream of gravel seemed to flow steadily through the middle of the gravel bank, the direction of its motion being the opposite of that of the

river. Sir D. Brewster made some experiments while looking out of rapid-moving trains on the effect of images moving rapidly across the retina, but he does not seem to have observed these motion spectra. Professor Silvanus P. Thompson has, however, observed a somewhat similar phenomenon.* He says:—"If, from a rapid railway train, objects from which the train is receding be watched, they seem to shrink as they are left behind, their images contracting and moving from the edges of the retina towards its centre. If, after watching this motion for some time, the gaze be transferred to an object at a constant distance from the eye, it seems to be actually expanding and approaching."

Under ordinary circumstances motion spectra are not easily noticed. Like form and colour spectra they require special precautions to be taken before they can be distinctly observed. I find, however, that these precautions are extremely simple, and that but little apparatus is required for showing them distinctly.

Simply take a circular cardboard disc,† painted as shown in fig. 1, and mount it on a horizontal shaft. Now, if, while this disc is being steadily rotated,‡ the eye is fixed upon it, and the motion continued a short time and then stopped, the disc will at once appear to begin rotating in the opposite direction. The experiment is, however, improved by painting either a copy of the disc, or a wheel, or any other object, on a sheet of paper, and hanging it up near the rotating disc. If, after looking at the rotating disc

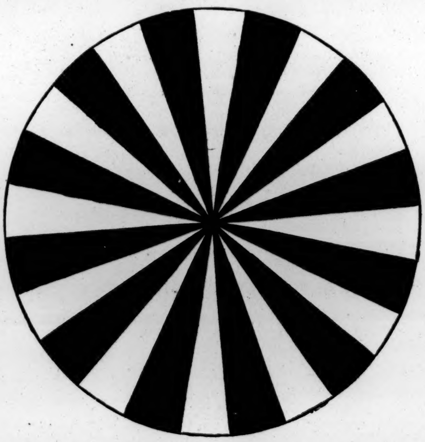


FIG. 1.

* Report of the British Association, 1877.

† The discs used in the experiments were from 22 cm. to 44 cm. in diameter. The number of parts into which the disc is divided does not seem to be of much importance. If divided into fewer parts, then it simply requires to be driven at a greater velocity. If divided into 24 parts, it can easily be driven quick enough with a handle on the opposite end of the shaft without the aid of multiplying gear.

‡ The disc should be rotated at such a rate that the eye cannot distinguish the black and white divisions, but not so quick that they are blended together.

for a short time, the eye is directed to the drawing, the wheel, or whatever it is, appears to be rotating in a direction the opposite of that of the exciting disc. Or we may vary the experiment, and look at a sheet of paper having a mottled surface.* When we do so, after looking at the rotating disc, we see a circular spectrum of the disc, in which the markings on the paper no longer appear stationary, but all seem moving in a circular direction, like a slow-moving whirlpool, the direction of the motion being the opposite of that of the exciting disc.

In these cases the motion was circular, and the result was a circular spectral motion. We may, however, vary the experiment, when we shall find that the spectrum will always correspond to the exciting motion. Suppose we take an endless band of paper, with black bars painted across it, and pass it over two drums revolving on horizontal shafts, one placed over the other, so that the paper band shall move in a straight line either upwards or downwards. If, while this band is in motion, the eye be fixed upon it for a short time and then the gaze be directed to the mottled paper, a spectrum of the moving band will be seen. A narrow strip of the mottlings will appear to flow through the mottled sheet of paper, reminding one strongly of the appearance of a lava stream, the breadth of the stream corresponding to the breadth of the moving paper band, and the direction of its apparent motion being the opposite of the moving band first looked at.

Or we may vary the experiment in this way:—Take a wheel, having spiral spokes coloured black, and rotate it in front of a disc similar to that first described, but in this case kept stationary, so that the white parts seem to travel from the centre to the circumference, or from the circumference to the centre of the disc, according to the direction in which the wheel is turned. If the mottled paper is looked at after looking at the apparatus in motion, all the mottlings in the spectrum seem to be in motion, either towards the

* The markings on the paper should not be too strongly contrasted with the paper. White paper roughly spotted over with ink will do, but the effect is greatly increased when the contrast is not so great. The best effect is produced by first washing the paper all over with Indian ink, thick enough to make the paper a darkish grey, and, while still wet, daubing it all over with Indian ink. In the absence of anything better, a cocoa-nut fibre mat does well.

centre or the circumference, according to the direction of the motion of the real impression.

These motion spectra are also seen if the eyes are closed after looking at the moving body, the spectrum of the moving paper band suggesting a phantom shower of rain in sunshine, the direction of the apparent motion being the opposite of that of the real impression.

It might be thought, since the spectrum of the moving band seen on the mottled paper seems to be in motion, and as some of the mottlings seem to flow past the others, that if we were to draw a straight line across the spectral stream, the line ought to appear bent, because it might be expected that the part of the line in the stream would appear to move forwards. Such, however, is not the case. So far as my experiments go, I have never seen the least appearance of a bend produced in a straight line; indeed, the straight line does much to stop the apparent motion. Again, in the first experiment with the circular disc, if we make the drawing at which we afterwards look larger than the exciting disc,—as, for instance, by extending the spokes of the wheel to a greater size than the rotating disc,—then this extension will entirely destroy all appearance of rotation, and the wheel will appear at rest. Do not these last experiments suggest that the seat of the illusion is deeper than the retina? I shall not, however, attempt to answer this question, as the experiments do not point to any definite conclusion.

Experiments were also made to determine the effect of influencing the whole retina. This was done by looking so closely at the moving band that its image covered the whole retina, but no decided effect was noticed. Experiments were also made with the same object by means of a large box-shaped arrangement, the sides of which were made of tracing paper having vertical bands of black paper 4 cm. broad and fixed 4 cm. apart. The observer being seated in a chair, the box was let down over him and put in motion, which was continued some time; the box was then raised, but no appearance of motion in surrounding objects was observed. There were, however, some curious effects produced by the rotation of this apparatus. At certain times, while surrounded by the rotating box, the observer felt as if rotating in the opposite direction. The most certain result, however, was a most disagreeable sickening effect,

which continued for some time after the experiment was made. The effect of this rotating apparatus might form an interesting study in connection with the important investigation at present conducted by Professor Alex. Crum Brown on the function of the semicircular canals of the ear.

3. On the Principles of the Logical Algebra; with Applications. Part I. By Alexander Macfarlane, M.A., D.Sc.

(Read 16th December 1878.)

(*Abstract.*)

In this memoir I examine the principles of the logical calculus of Boole, as laid down in his celebrated treatise on the "Laws of Thought," and also the criticisms which have been published concerning these principles. I bring forward a new theory of the operation of the mind, founded upon an analysis of language and the nature of mathematical reasoning, which enables me to correct these principles, to place them on a clear, rational, and generalised basis, and to show that there is a logical algebra which coincides with the ordinary algebra when its symbols are integral, but is a generalised form of the ordinary algebra when its symbols are fractional. Hence all the theorems in ordinary algebra when generalised properly are true in the logical algebra. I show the analytical meaning of the axioms of logic and their relation to the algebraic axioms of operation. By means of this algebra I investigate the theory of immediate inference, and also the conclusions and numbers of conclusions of different kinds which can be deduced from premises of certain given forms. The memoir also professes to prove a great number of new theorems in the theory of necessary and probable inference.

4. Note on Ulodendron and Halonia. By Mr D'Arcy Wentworth Thompson. Communicated by Sir Wyville Thomson.

Monday, 6th January 1879.

Professor KELLAND, President, in the Chair.

The following Communications were read:—

1. Notes on some Experiments with the Telephone. By James Blyth, M.A.

While experimenting with an ordinary Bell telephone, of small resistance, I found that it was able to reveal the existence of electric currents produced by the mere friction between conducting substances. This was shown in the following way. Two files had wires firmly connected to them, and were thereby attached to the terminals of a telephone circuit in a distant room. When these files were rubbed against each other, a most distinct grating noise was heard in the receiving telephone. In order to find if this sound varied, when different substances were rubbed together, the following plan was adopted. A wire was firmly attached to a small table-vice, and led to one of the terminals of the telephone circuit, while the wire from the other terminal was attached to a clamp into which any substance, which it was desired to test, could be screwed. Different substances were then screwed into the vice and clamp, and rubbed against each other by an assistant, in each case, as far as possible, with the same pressure. By listening attentively in the receiving telephone, I endeavoured to detect any variation in the sound as the assistant passed from one substance to another. As far as I could judge, little or no variation was produced when the following substances were rubbed on themselves and on each other, viz. : steel, brass, iron, zinc, lead, gas carbon, copper, with possibly the exception of copper on iron, which, I thought, gave the sound a little louder.

It was different, however, when two pieces of antimony and bismuth were rubbed together. In this case the sound was decidedly louder. I tried also, with a very distinct effect, antimony rubbing on gold, and antimony on silver.

In order to augment the currents, and consequently the sounds produced in this way, I took a large iron fly-wheel mounted on an axis which ran in centres. By a wire attached to one of the centres this wheel was connected to one of the terminals of the circuit, while a file was connected to the other terminal. The wheel was then driven rapidly round, and the file held hard on to its rim,—so hard that sparks of fire were produced by the friction. In this way a very distinct noise was heard in the receiving telephone. I have also made a variety of the above experiment by mounting a small cylinder of antimony in a turning-lathe, and driving it round against a bar of bismuth. This produces the loudest and most distinct noise of anything which I have yet tried.

These experiments demonstrate, without doubt, the existence of currents produced in conducting substances by friction alone, but it becomes a question whether they are to be regarded as merely thermo-electric, or whether they are not the very currents referred to by Sir William Thomson as the probable cause of friction, and by Professor Tait, in his "Thermo-dynamics," where he says, "it is possible that all friction, not excepting that caused by actual abrasion, is due to the production of electricity."

Instead of rubbing the substances together, I next proceeded to try the effect of knocking the one against the other. For this purpose a small anvil was put into metallic connection with one of the terminals of the circuit, and a hammer similarly connected to the other. Each stroke of the hammer on the anvil was very faintly heard in the distant telephone. As a variety of this experiment I put a small quantity of detonating powder on the anvil, and came down upon it with a blow from the hammer. I thought that it might be possible to hear something of the sharp snap produced by such a blow. The sound, however, heard in the telephone was not appreciably louder than before. Another variety of this experiment was made by driving a wheel, with large teeth, rapidly round in the turning-lathe, and holding against it a strong metal spring. The rapid clicks produced in this way were heard even when the telephone was a short distance from the ear. Here, however, it is plain that we have a mixture of the effects produced by rubbing and knocking.

In my next experiment I took a phonograph, and so arranged it

that a telephone circuit was completed through the spring which carries the pricker, the pricker itself, and the cylinder. When the pricker was allowed to press hard into the groove, and the cylinder turned, a faint grating noise was heard in the telephone, unless at those points where there happened to have been regular serrate markings left by the tool in cutting the groove, and then, as the pricker passed over these, a sound more or less resembling a feeble attempt at an articulation was heard. I then put a sheet of tinfoil on the phonograph cylinder, and spoke a sentence loud and distinct into the mouthpiece, and, for the purpose of increasing the sound, as heard in the telephone, I also included two Bunsen's cells in the circuit. When the phonograph was now turned, so as to reproduce the sentence, the articulation was heard in the receiving telephone, loud enough certainly, but considerably marred by the mere rasping of the pricker on the natural inequalities of the tinfoil.

It is obvious that, in this experiment, the articulation, such as it is, heard in the telephone must be caused by the variation in the resistance to the current, which arises from the unequal pressure of the pricker upon the tinfoil as it follows its indentations. This has, I think, an important bearing upon the character of all curves got by different processes of enlargement from the tinfoil record. Such curves could only accurately correspond to the movements of the disc which produced the indentations, provided the style attached to the lever, for producing the enlargement, pressed exactly on the tinfoil as the pricker did. Now, seeing that the pricker does not press equally at all times on the tinfoil, it would be very difficult, if not impossible, so to arrange a style and enlarging lever as to press in a manner so exactly similar.

The telephone can be employed to illustrate, in a very pleasing way, the incipient stage in the breaking-up of a liquid vein into globules. For this purpose a vein of acidulated water is made part of a telephone circuit, which also includes one or two Bunsen cells. This is easily managed by attaching a metallic can, having a small orifice in its bottom, to one of the terminals of the circuit, and a shallow metallic basin to the other. The first vessel, being now filled with acidulated water, is held over the basin, so that the column of water from the orifice flows into it, and so completes the electric

circuit. By gradually raising or lowering the upper vessel, a longer or shorter column of liquid can be made part of the circuit. On listening in the telephone, so long as the liquid vein is short and limpid, no sound whatever is heard. This shows that the electric current has uninterrupted circulation. On gradually lengthening the liquid vein, a point is reached when a rattling noise is heard in the telephone. This arises from the altered resistance caused by the liquid vein beginning to break up into globules. On still farther lengthening the vein, a point is very soon reached when all sound in the telephone again ceases. This corresponds to the stage when the liquid vein has actually separated into detached drops, and so broken entirely the electric circuit.

2. On the Measurement of Beknottedness. By Professor Tait.

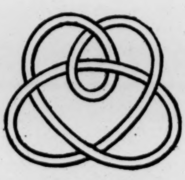
(*Abstract.*)

In my former papers on the subject of Knots, I have provisionally measured *Beknottedness* by the smallest number of changes of sign at the crossings, which will render all the crossings nugatory.

Though I have not seen occasion to doubt the accuracy of this mode of measurement, there are two objections to it—(1) It is very difficult of application in complex cases; (2) It suggests no direct relation to the electrodynamic method which, except in the case of knots wholly or partially amphicheiral, gives results quite in accordance with it.

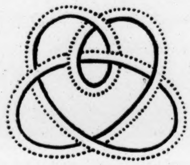
The object of the present paper is to describe a method which, while at least partially meeting these objections, very considerably simplifies some of the more important processes for the treatment of knots, which I have already given.

In this abstract a very simple example will suffice to indicate the method. Take the following six-fold knot



and modify the sketch, as on next page, the dotted line being traced always on the *right-hand side* of the full line as we go round the curve.

[In practice, the dotted line may conveniently be drawn with a coloured pencil or crayon.]



A little consideration shows that—

1. Of the four angles at each crossing, one is enclosed between full lines, and its vertical angle by dotted [coloured] lines. These will be called the *symmetrical* angles.

2. The crossing is electrodynamically positive if it is *over to the right* in the *symmetrical* angles, and *vice versâ.*

[In the figure the two interior crossings alone are positive.]

3. If the knot be cut through along a line dividing the *symmetrical* angles at any crossing, and the pairs of ends on either side of that line be reunited, the whole remains a knot, with one crossing less than before (Proc., 1877, p. 322). If the line divide the *unsymmetrical* angles, the whole becomes a link.

[Dividing the figure at the upper crossing, it becomes either the twist of five-fold knottiness, or the trefoil knot once linked with a simple ring.]

These methods are in practice very much superior in convenience of application to those I have already given, especially when the knot to be reduced is complex.

The paper contains rules for the calculation of the beknottedness of the original knot, in terms of the beknottedness and belinkedness of these reduced forms; so that knottiness n is made to depend upon $n - 1$. I have not yet succeeded in obtaining from these a general expression such as will take account of all the successive reductions of a knot to zero of knottiness.

3. Preliminary Note on the Measurement of the Thomson Effect by the Aid of Currents from the Gramme Machine. By Professor Tait.

4. On the Disruptive Discharge of Electricity. By Alexander Macfarlane, D.Sc., and P. M. Playfair, M.A.

(*Abstract.*)

During the months of November and December of this Session we have investigated certain questions suggested by the results already communicated to the Society.

Difference of Potential required to pass a spark between (1) *two equal spherical balls at different distances,* (2) *a plate and ball at different distances, and* (3) *a plate and point at different distances.*

A series of observations was taken for each of these, and on three successive days, without altering the arrangement of the apparatus or the charge of the electrometer. The couple of small Leyden jars were attached to the conductors of the Holtz machine, as we had previously found that it was impossible to observe the discharge between a plate and point with any degree of accuracy when the capacity was small.

Two Balls, each of $\frac{2}{3}$ *inch diameter.*—The series of observations for the two balls is a more minute and extended investigation of a problem we took up and solved approximately before. We have observed more minutely the values of the readings at the smaller distances, and also noted the cause of the irregularity at the ends. We found that at 80 mm. small violet sparks began to pass before the principal white spark, and that the reading was then more ambiguous than for smaller distances. Escape from the conductor was first noticed at 120 mm.*

Plate and Ball.—We employed a tin plate 8 inches diameter, and one of the brass balls used in the previous experiment. The curve obtained is not very different from that for the two balls; it is somewhat more circular. Small sparks passing before the large one were observed to begin at a shorter distance than in the previous case. Another irregularity at the end was due to the passing of two large sparks. Finally, the electricity began to escape from the insulated wires.

Plate and Point.—The plate used was the tin plate of the pre-

* Hence the irregularity previously observed is not due to the escape of electricity into the air, but to the passage of small sparks between the electrodes.

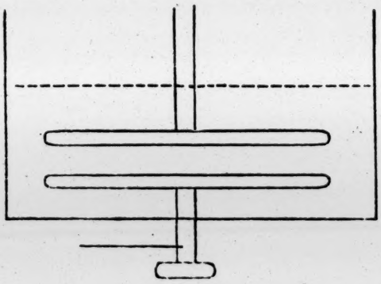
vious experiment; the point was conical and of brass. From 1 to 5 mm. the discharge was in the form of a white spark; for higher distances nothing was visible excepting a glow at the point. The series was continued up to 200 mm., as there was no difficulty due to escape of the electricity into the air.

Discharge through a Solid Dielectric.—We obtained, by favour of Mr Calderwood, of Addiewell Chemical Works, a quantity of a pure solid paraffin of low melting point. The plate electrodes were separated to a distance of $\frac{1}{3}$ inch inside a glass vessel, the liquefied paraffin poured in so as to cover the plates completely, and then allowed to solidify for twenty-four hours. When the plate electrodes were charged the first spark which passed was large and illuminated the whole of the paraffin; but the succeeding discharges were much smaller, and of equal amount. The first spark produced a deflection 3·6 times as great as the succeeding sparks. When the plate of paraffin was examined afterwards, it was found to be perforated in a zigzag manner, the hole being surrounded by char. We found that—

Electric Strengths.

Air, ...	1
Paraffin when solid, ...	5
Paraffin when liquid, . . .	2·5

Thus the electric strength of this substance, when in the solid state, is to its electric strength when in the liquid state as 2 to 1.



As an instance of how these experiments may be made directly useful, I may mention that we obtained two samples of liquid paraffin from Mr Calderwood to compare their electric strength. We found the ratio to be 1·6. It is, however, extremely difficult to effect the comparison unless we have a considerable quantity of each specimen. It is best to have a dish of the above form, where we can

have broad plates, the lower one slightly raised above the glass bottom, and the upper one well immersed in the liquid. The former of these conditions helps to prevent solid particles getting in between the plates, and the latter prevents the rising of the liquid up the stem, and consequent splashing about of liquid particles.

Discharge through Paraffin Vapour.—We put the discharging vessel, with a quantity of one of the pure liquid paraffins, inside the receiver of an air-pump, exhausted the air, and allowed the paraffin vapour to accumulate. When the barometer-gauge indicated 50 mm. pressure, the distance being $\frac{1}{3}$ inch, we took sparks through the vapour. The spark was of a broad section, green at either end, but of a deep violet between. When a quantity of air was let in, white jagged sparks were observed in the midst of the coloured spark. From the readings obtained at 50 mm. pressure, we infer that this paraffin vapour is 1·7 times as strong as air.

5. Laboratory Note. By Professor Tait.

Last autumn I received from Mr Maclachlan of Lower Green, Mitcham, some specimens of india-rubber tape which had been for several years wound, under considerable tension, helically round copper wire. At ordinary temperatures, after being peeled off, the material shows no tendency to contract; but Mr Maclachlan found that in hot water it almost instantly resumes its original dimensions.

I have recently reproduced almost exactly the same results by stretching sheet india-rubber, slightly warmed, helically round glass tubes, and immersing it for a short time in a freezing mixture. Some of the specimens thus produced in a few minutes compared favourably in their after behaviour in hot water with those of Mr Maclachlan.

Even without the use of a freezing mixture the effect may be produced, though not so perfectly, by drawing out the heated india-rubber to the point at which its intensibility begins to diminish very rapidly. If it be held for a few seconds in that state of extension, it shows very little tendency to contract till it is immersed again in hot water. Then it is instantly reduced to one-fourth or one-fifth of its previous length, but remains permanently stretched to three or four times its original length. This operation may be

performed many times in succession on the same specimen with the same results.

Professor Clerk-Maxwell informs me that similar results are to be obtained with gutta-percha, drawn out when *cooled,* after being boiled in water.

The subject is especially interesting as an exaggerated example of the *Elastische Nachwirkung,* which has recently been discussed at great length by Boltzmann and others.

The following Gentlemen were duly elected Fellows of the Society:—

J. B. BROWN MORRISON, of Finderlie and Murie, Perthshire.
ANDREW WILSON, Ph.D., 118 Gilmore Place.
JAMES LAMBERT BAILEY, Ardrossan.
ROBERT COX, Gorgie, Murrayfield.
JOHN HISLOP, Sec. to the Dep. of Education, New Zealand.
JAMES COSSAR EWART, M.D., 12 Alva Street.
GEORGE WM. BALFOUR, M.D., 17 Walker Street.

Monday, 20th January 1879.

DAVID STEVENSON, Mem. In. C.E., Vice-President, in the Chair.

The following Communications were read:—

1. On the Action of Heat on the Salts of Trimethyl-sulphine. No. III. By Professor Crum Brown and J. Adrian Blaikie, B.Sc.

I. *Acetate of Trimethyl-Sulphine.*

The acetate is formed by treating the iodide of trimethyl-sulphine with acetate of silver. On leaving the strong solution over sulphuric acid *in vacuo* for three weeks no crystallisation took place. The syrup on being heated in a small retort gave off water, and, without solidifying, sulphide of methyl, mixed with acetate of methyl. On redistilling the two latter, they went over at a temperature between 45°

and 56° C. It was not possible to separate them by distillation, but on shaking the mixture with solution of chloride of mercury, the sulphide of methyl was removed, leaving a few drops of acetate of methyl, easily recognised by its fruity smell.

$$(CH_3)_3S—C_2H_3O_2 = (CH_3)_2S + (CH_3)—C_2H_3O_2 .$$

II. *Benzoate of Trimethyl-sulphine.*

The benzoate is formed by treating the iodide of trimethyl-sulphine with benzoate of silver. The solution of the salt can be evaporated on the water bath to a syrup. On leaving it for about two weeks over sulphuric acid a very few crystals were formed, which could not be separated from the very thick syrup in which they were suspended. By adding alcohol it was obtained more easily in small thin plates. After several days of very cold weather a crust formed over the surface of the aqueous solution.

The thick aqueous solution on being heated to 100° C. with a current of dry air passing over it gave off some water, but the salt did not solidify. On continuing to heat at about 110° C., the clear liquid became milky, sulphide of methyl was given off, and a layer of a liquid formed above the heavy aqueous solution. This was collected apart, dried by means of chloride of calcium, and gave as its boiling point 198° C., that of benzoate of methyl. The decomposition is expressed by the following equation :—

$$(CH_3)_3S—C_7H_5O_2 = (CH_3)_2S + (CH_3)—C_7H_5O_2 .$$

III. *Dithionate of Trimethyl-sulphine.*

The dithionate is formed by neutralising an aqueous solution of free dithionic acid with the hydrate of trimethyl-sulphine. On evaporating a solution of the salt on the water bath it begins to crystallise out. On leaving the saturated solution to cool, a large quantity of clear cubical crystals was obtained, not hygroscopic, insoluble in hot alcohol, and, when dry, without any smell of sulphide of methyl.

Analysis agrees with the formula

$$\{(CH_3)_3S\}_2S_2O_6,\ H_2O.$$

On heating the salt to about 120° C., it loses water, and on raising the temperature to 220° C. sulphurous acid is given off, but at first no sulphide of methyl. After some time, sulphide of methyl begins to come off also, and the substance melts. Heat was applied until the melted substance, which had been perfectly clear, turned slightly brown, and the evolution of gas almost ceased. 8·015 grammes were found to have lost 3·325 grammes = 41·4 per cent. The loss of one molecule of water, one of sulphurous acid, and one of sulphide of methyl, corresponds to 43·3 per cent.

On cooling, the liquid solidified. The crystalline mass was very hygroscopic, and dissolved in alcohol. On adding ether, the salt was precipitated as a strong aqueous solution, which, on standing over sulphuric acid, yielded beautiful long fine prismatic needles. These were separated as well as possible from the mother liquid, by pressing between filter paper, and left for several days over sulphuric acid.

Analysis agrees with the formula

$$\left.\begin{matrix}(CH_3)_3S\\ CH_3\end{matrix}\right\}SO_4$$

and an examination of its properties proved it to be the methyl sulphate of trimethyl-sulphine.

$$(CH_3)_3S—O—SO_2—SO_2—O—(CH_3)_3S =$$
$$(CH_3)_2S + SO_2 + (CH_3)—O—SO_2—O—(CH_3)_3S.$$

2. Experimental Determination of the E. M. F. of the Gramme Magneto-Electric Machine at different Speeds. By Professor Tait.

3. On the Law of Cooling of Bars. By Professor Tait.

[Part of this paper appears in the *Transactions* for 1877–78, having been inserted (as § 11*) in Professor Tait's paper on *Thermal and Electric Conductivity*.]

4. Note on the Distribution of Temperature under the Ice in Linlithgow Loch. By J. Y. Buchanan, M.A.

The following observations of the temperature of the water at different depths below the ice covering Linlithgow Loch were made with one of Messrs Negretti & Zambra's "half-turn" self-registering thermometers, which proved to be a useful instrument for this species of inquiry. It was necessary, however, to fit it with a suitable inverting contrivance, as this part of the apparatus supplied by the makers is quite useless. The temperatures have received a provisional correction for error of graduation, and they may still have to receive a further, though certainly very slight, rectification, when a thorough comparison with a Kew standard has been made. The results are given in the table, to which are appended particulars of position and date corresponding to the stations.

Depth, Feet.		Temperature, Fahrenheit, at Station			
		No. 1.	No. 2.	No. 3.	No. 4.
	3	34·90	...	...	35·90
	6	35·25	36·10	36·00	36·30
	12	37·15	36·80	36·85	36·80
Bottom, . .	16	...	...	37·40	
Mud, . . .	16	...	...	37·80	
Bottom, . .	16½	38·50			
	18	...	36·95	...	36·90
	24	...	37·30	...	37·30
	30	...	37·40	...	37·40
	36	...	37·60	...	37·70
	42	...	...	...	38·40
	44	...	38·60		
Mud, . . .	46	...	...	...	39·85
Mud, . . .	47	...	39·75		

Particulars of Stations.—No. 1. Position approximately 70 or 80 yards from the steep bank below the Palace, which bears about S.S.E.* No actual bearings were taken, as my object was to test the action of the thermometer.—Date 6th January 1879.

* The bearings given are magnetic, and were taken with a pocket azimuth compass.

No. 2. Flagstaff on top of Town-hall bore . N. 160° E.
N.W. gable of Palace . . N. 125½° E.
Date 9th January 1879.

No. 3. Flagstaff on Town-hall bore . . N. 154° E.
Centre of Rickles Island . . N. 63° E.
Date 9th January 1879.

The "bottom" temperature is that of the water a few inches from the mud. The "mud" temperature is that indicated by the thermometer when resting in the mud.

On this day, although a piercingly cold wind was blowing, the surface of the ice was thawing, and its structure could be observed. At Station No. 2, it was rendered quite opaque by air-bells, while at No. 3, these were present in much smaller quantity.

No. 4. Flagstaff on Town-hall bore . . N. 147° E.
Centre of Rickles Island . . N. 64° E.
Date 11th January 1879.

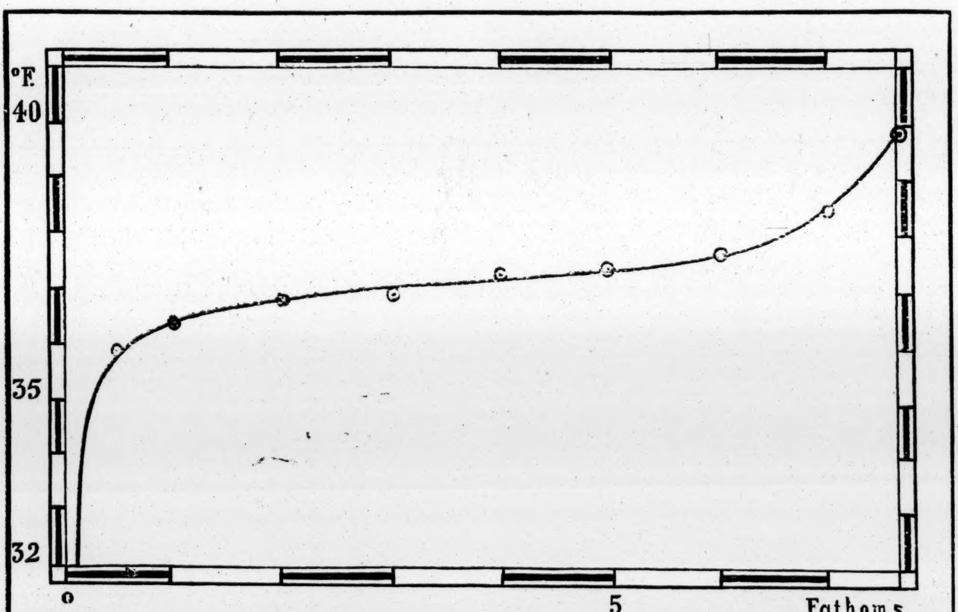
The ice at the surface was found to be 8½ inches thick, and it was covered with a layer of freshly fallen snow 2 inches thick. The air was crisp and frosty.

No. 5. Flagstaff on Town-hall bore . . N. 152° E.
Centre of Rickles Island . . N. 65½° E.
Date 20th January 1879.

Here a sample of the water was collected from a depth of 10 feet below the ice. No temperature observations were made.

The observations on the 6th January 1879, at Station No. 1 were made principally with a view to test the action of the thermometer and the inverting apparatus, and also to determine at what depth the water would be found at the temperature corresponding to its maximum density. The result of this day's operations was to show that the thermometer was suitable for such work, and to indicate two remarkable conditions of the water of the loch; namely

first, that the temperature above alluded to, 39·2° Fahr., was not observed at all at any depth between the ice and the bottom; and second, that the curve representing the vertical distribution of temperature had a point of contrary flexure, showing that the actual distribution could never have resulted from the freezing of a thin layer on the surface of a large volume of water at a uniform temperature, and the further cooling of it by conduction from the lower ice surface. The observed temperatures showed that, if the water had ever been at a uniform temperature throughout its depth, that temperature was certainly much below 39·2°, and that while the



water was being cooled by conduction downwards from the ice, it was being warmed by conduction and convection upwards from a source of heat at the bottom.

These unexpected results induced me to repeat my visits to the loch, and the observations at Stations Nos. 2, 3, and 4 were made on the 9th and 11th January. It will be seen that the results of them fully bear out the conclusions derived from the preliminary observations at Station No. 1. At Stations Nos. 2 and 4, situated in the deep western basin of the loch, the suspected heating surface is separated by a sufficiently thick stratum of water to enable its action to be studied separately. The observations at No. 4 are

represented graphically by the curve. From it we see that the temperature rises very quickly in the first fathom, then very slowly for some distance, until, in the neighbourhood of the bottom, it again rises quickly, reaching 39·85° in the mud. Had the water of the loch been in the condition usually imagined to immediately precede freezing—that is, at the temperature at which its water attains a maximum density uniformly throughout its depth, we should expect to find in the distribution of temperature in the water after the formation of ice the *remains* of this condition. The condition referred to would be represented graphically by a straight line drawn parallel to the line of depths through the temperature of maximum density, and if there were no supply or removal of heat from any other quarter than the surface, the curve of temperatures at any subsequent time when the loch was covered with ice would tend to coincide with this line at a sufficient depth. The source of heat which these observations show to exist at the bottom of Linlithgow Loch would have a tendency to mask but not to obliterate these remains. If the curve of Station No. 4 be studied in this light we discover the remains of a comparatively uniform temperature of approximately 37°, more than half the water being at a temperature between 36·5° and 37·5°. If we imagine the water to have been at a certain date uniformly at the temperature 37°, and the surface to have been suddenly covered with ice, and at the same time a source of heat to have been applied at the bottom, the distribution of temperature shortly afterwards would, I think, be of the kind represented in the curve. It must be observed that, assuming the water to be pure, both the loss of heat from the surface and the supply of it from the bottom would affect the intermediate waters by conduction alone until the temperature of the bottom had been raised to 39·2°. In the present case this temperature has just been passed, and, admitting the water to be pure, convection would be beginning to come into play. That it has begun to do so is shown by the flatness of the curve near the bottom, compared with its steepness near the ice.

Having established the existence of this unexpected thermal state of the water, it was necessary to find an explanation. The first that occurred to me was to suppose that the water of Linlithgow Loch was not pure water, but contained dissolved ingredients

sufficient to bring its temperature of maximum density down from 39·2° to about 37°. Three or four parts of common salt dissolved in one thousand parts of the water would be sufficient to produce this effect, and it did not seem extravagant to look upon this as the probable solution of the problem, especially as the loch is the receptacle for the whole sewage of the town of Linlithgow and the refuse of several works. Accordingly, on the 20th January, a sample of water was drawn from a depth of ten feet below the ice at Station No. 5, and examined. My supposition appeared likely to be confirmed by the overpoweringly horrible stench emitted by the water, which argued an amount of pollution not inconsistent with a large quantity of dissolved saline matter. On examination, however, it was found to be otherwise.

When freshly drawn the water was clear, but had become slightly turbid by the time it reached the laboratory; this turbidity disappeared on diluting the water with a large quantity of alcohol. It reacted neutral to test-papers. Its specific gravity was 1·00035 at 39·9° F., that of distilled water, at the same temperature, being unity.

The smell of the water was removed by boiling. Neither sulphate of copper nor alkaline acetate of lead solutions produced any precipitate of sulphides.

Finally, the water contained only 0·03 grammes chlorine in a litre, and was evidently remarkably free from saline ingredients.

It remains to determine by experiment the actual temperature at which this water attains a maximum density, and also, by observations in other lochs, whether a similar distribution of temperature is to be found.

Considering the excessively foul state of the loch, and especially of the mud at the bottom of the western part, the evolution of heat cannot be wondered at.

It will be seen from the table that the observations made at No. 2 on the 9th agree substantially with those made at No. 4 on the 11th January. At Stations Nos. 1 and 3 the depth of the water is nearly identical, but the temperatures at the same depths are different. At No. 1 the water near the surface is colder, and that near the bottom warmer than at No. 2. At No. 1 the temperature of the mud was not observed, but it would no doubt be

high, as that of the water a few inches above the bottom was 38·5°; the same water at No. 3 being 37·4° and the mud 37·8°. No. 1, being on the slope next the town, is exposed to the filth to be derived from it; it is therefore not surprising that the bottom water is warmer than at No. 3, which is situated on the banks near the northern shore, where the water is comparatively clear.

On the Principles of the Logical Algebra; with Applications. Part II. By Alexander Macfarlane, M.A., D.Sc.

(Read 20th January 1879.)

(*Abstract.*)

The equation

$$x^2 = x$$

expresses the condition that the symbol x be single and positive. The equation

$$x^2 = -x$$

expresses the condition that the symbol x be single and negative. The principle of contradiction

$$x(1-x) = 0$$

can be legitimately deduced with the help of the fundamental axioms of the science.

The memoir contains a general investigation of the conclusions which can be drawn from two or more premises:—

(1) of the form

$$x = m;$$

(2) of the form

$$xy = m;$$

(3) of the form

$$x = y + z;$$

and investigates the fundamental relations which subsist between single functions of any number of independent symbols.

Monday, 3d February 1879.

DAVID MILNE HOME, LL.D., Vice-President, in the Chair.

The Keith Prize for the biennial period 1875–77, which has been awarded to Professor HEDDLE, for his papers on the "Rhombohedral Carbonates," and on the "Felspars of Scotland," originally communicated to the Society, and containing important discoveries, was presented by the President (Professor Kelland) with the following remarks:—

PROFESSOR HEDDLE,—I am here to-night to exemplify a remark which is often made, that to insure success in an address such as I am about to deliver, the best way is to commit the charge of it to one absolutely ignorant of the subject. No false pride will then stand in the way of the best sources of information, nor will any undue admixture of half knowledge clog and darken the truth. For every particular contained in these remarks, then, I at once unhesitatingly acknowledge myself indebted to Professor Geikie. When I first became acquainted with this Society forty years ago, there used to frequent our meetings men who had the reputation of being mineralogists rather than geologists—Lord Greenock, Allan, and probably Jameson himself. That race has now died out, and with them mineralogy as a distinct science has all but lain dormant amongst us. During the preceding quarter of a century that science had flourished nowhere more vigorously than in Edinburgh. Professor Jameson introduced the definiteness and system of the Freyburg school, and infused into his pupils such a love of minerals that numerous private cabinets were formed; while under his fostering care the University Museum grew into a large and admirable series. One of my first acts as Professor in the University was to vote out of the Reid Fund, which had just come into our hands, a large sum (some thousands) to pay back monies expended on minerals throughout a series of years preceding. During those years geology, as the science is now understood, hardly existed. For as the nature and importance of the organic remains embedded in the rocks became recognised, their enormous value in the

elucidation of geological problems gradually drew observers away from the study of minerals. Consequently, as palæontology increased, mineralogy waned among us. To such an extent was the study of minerals neglected, that geologists even of high reputation could not distinguish many ordinary varieties. But as a knowledge of rocks presupposes an acquaintance more or less extensive with minerals, the neglect of mineralogy reacted most disadvantageously on that domain of geology which deals with the composition and structure of rocks. The nomenclature of the rocks of Britain sank into a state of confusion from which it is now only beginning to recover. To you, Professor Heddle, belongs the merit of having almost alone upheld the mineralogical reputation of your native country during these long years of depression. You have devoted your life to the study, and have made more analyses of minerals than any other observer. You have not contented yourself with determining their composition and their names; you have gone into every parish in the more mountainous regions, have searched them out in their native localities, and by this means have studied their geological relations, heaping up evidence from which to reason regarding their origin and history. After thirty years of continuous work you have communicated the results of your labours to this Society. For the first two of these papers, "On the Rhombohedral Carbonates," and "On the Felspars," in which you have greatly extended our knowledge of pseudomorphic change among minerals, enunciating a law of the shrinkage so frequently resulting therefrom, the Society proposes now to express its gratitude to you. The value of your papers is undoubted. Through the kindness of Mr Milne Home I have been favoured with the sight of letters addressed to you by four eminent mineralogists—Dana, of America; Rammelsberg, of Berlin; Szabo, of Buda-Pesth; and King, of Queen's College, Galway. Szabo states that the notice of Professor Heddle's paper on the Feldspars which appeared in Groth's "Zeitschrift für Mineralogie," greatly interests him, and makes him desirous of placing himself in direct communication with the author. Dana says, "I have read your paper on the Feldspars, in the 'Transactions' of the Royal Society of Edinburgh, with great satisfaction. Your thorough method of work leads towards important results of great geological as well as mineralogical value." I have the satis-

faction, in name of the Council of this Society, of presenting you with the Keith Medal. It is hoped that this recognition of your labours will not be without encouragement to you in the arduous researches in which you are engaged.

The following Gentlemen have been recommended by the Council to fill the vacancies in Foreign Honorary Fellowships caused by the deaths of Claude Bernard, Elias Magnus Fries, Henri Victor Regnault, Angelo Secchi:—

Frank Cornelius Donders, Utrecht.
Asa Gray, Cambridge, U.S.
Jules Janssen, Paris.
Johann Benedict Listing, Gottingen.

The following Communications were read:—

1. Chapters on the Mineralogy of Scotland. By Professor Heddle. Chapter V.

(*Abstract.*)

In this chapter Dr Heddle considered *the micas* occurring in Scotland. These he found to be Muscovite or Muscovy glass, and margarodite—of the white micas; Biotite, lepidomelane, and a new species which he proposes to call Haughtonite, after Professor Haughton of Dublin—of the dark micas. He also finds the species pihlite, hitherto unrecognised in Britain, occurring in quantity in the central districts of Banffshire, and in the west of Aberdeenshire.

In connection with the first of these micas, the mode of formation of exfiltration veins, and the metamorphism of gneiss into the grey granite of Aberdeenshire, were considered.

Dr Heddle found that margarodite is the glistening constituent of all the so-called talc slates which he had analysed; he doubts the occurrence of the last-named rock in Scotland, as no one of the rocks which he has examined, and which have passed by that name, was found to contain any talc.

Biotite in Scotland is characteristic of granular limestones, which also rarely contain margarodite. Lepidomelane, the ordinary dark-granite mica of Ireland, he had found in Scotland in only two localities.

Haughtonite, which is a ferrous oxide mica, with little magnesia, he finds to be the mica special to most of the grey and pale-coloured granites of Scotland; and it also occurs in the diorites of Banffshire. This new mica likewise occurs somewhat rarely on the Continent, though hitherto unrecognised as a distinct species.

2. On the Carboniferous Volcanic Rocks in the Basin of the Firth of Forth—their Structure in the Field and under the Microscope. By Professor Geikie, F.R.S.

(*Abstract.*)

In the introductory portion of the paper a sketch is given of the present state of opinion among Continental petrographers regarding volcanic rocks associated with palæozoic formations. The author points out that a relic of Werner's belief in the recentness of volcanic action may still be traced pervading the ideas of German geologists. In this paper he endeavours to show that, alike in their formation in the field and in their structure under the microscope, the basalts and tuffs of palæozoic time were as truly the products of volcanic action as the lavas and ashes of the present day. The area selected for description is the basin of the Firth of Forth. After an outline of the labours of previous observers in this classic region, the author sketches the history of volcanic action there, showing that volcanoes abounded and threw out an enormous pile of material during the time of the Lower Old Red Sandstone. After a long period of quiescence, the subterranean disturbances were renewed in an early part of the Carboniferous period, and continued until near the close of the deposition of the Carboniferous Limestone series. It is with the history and the products of this second volcanic epoch that the present communication deals.

The paper is divided into two parts. The first of these treats of the history of volcanic action during the Carboniferous period in the basin of the Firth of Forth. That area consists of six volcanic districts, in several cases remarkably independent of each other; and, though separated only by a few miles, yet producing very distinct forms of lava and tuff. The structure of the volcanic rocks in the field is then traced. Detailed descriptions are given

of some of the more typical necks or volcanic funnels which supplied the sheets of rock now so abundant at the surface, and comparisons are drawn between their characters and those of tertiary and recent cones and craters. The numerous intrusive sheets and dykes are described in their relation to the surrounding rocks and to the position of the volcanic vents. An account is given of the bedded lavas and tuffs so copiously interstratified with the Carboniferous formations, and their identity with modern volcanic masses is insisted on.

The second part of the paper deals with the petrography of the igneous rocks, and more especially with their characters as revealed by the microscope. The author states that he has been engaged during the last ten years in carrying on this investigation, and that he has studied some hundreds of slices of the rocks from all parts of the region. After alluding to what has been published by other observers on this subject, he proceeds to describe the rocks under the two main divisions of, I. Crystalline; II. Fragmental.

I. Crystalline.—These embrace all the melted or lavaform rocks. They may be subdivided into four classes:—1st, *Augite-Felspar Rocks*, which include three types of structure—(1) granitoid, consisting of a crystalline mixture of a triclinic felspar (but sometimes orthoclase), augite, titaniferous iron, and apatite, with occasionally biotite, and more rarely quartz; (2) Doleritic—a crystalline mixture of triclinic felspar and augite, with titaniferous iron or magnetite, apatite, and frequently olivine, with a variable proportion of a half-glassy ground-mass; (3) Basaltic—a mixture of minutely granulated (and larger, more definitely crystallised) augite, triclinic felspar, magnetite, and olivine, with usually some apatite in a glassy or half-glassy ground mass. 2d. *Olivine* (*Serpentine*) *Augite Rocks*, consisting mainly of serpentine throughout, while abundant crystals of altered olivine occur, fresh augite, titaniferous or magnetic iron, apatite, and occasionally traces of a triclinic felspar. Where the last-named mineral increases in amount, the rock assumes the character of a much altered "diabase." 3d. *Felspar-magnetite Rocks*, consisting essentially of a triclinic felspar and grains or shred-like particles of a black magnetic mineral, sometimes with large orthoclase crystals, rarely with augite, in a porphyry ground-mass. 4th. *Orthoclase Rocks* or *Felsites*.

II. Fragmental.—The rocks included in this class embrace all the agglomerates, breccias, and tuffs. Their characters are described in detail, and it is shown that they consist mainly of the granular *peperino* or detritus of the lavas.

3. Exhibition of Specimens of Auriferous Quartz from the Leadhills District By Patrick Dudgeon, Esq. of Cargen.

(*Abstract.*)

Mr Dudgeon exhibited some specimens of auriferous quartz from Wanlockhead and Leadhills districts.

No. 1 was found in July 1878, by Thomas Tennant in Wingate burn, Leadhills; it is a very rich specimen, and is now placed in the collection of Scotch minerals in the Museum of Science and Art.

No. 2 was found by Eleanor Handcock in April 1878, on the banks of the Wanlock water, Duntercleuch.

No. 3, found by E. Benzie, daughter of police constable at Leadhills, in Glengonar water, Leadhills, in 1878.

No. 4, found in Longcleuch Burn, Leadhills, and in the possession of Mr Joseph Gill, local factor to the Earl of Hopetoun.

Declarations as to No. 1 and 2 made before a Justice of Peace, as to the place and date they were found, accompanied the specimens.

The following Gentlemen were duly elected Fellows of the Society:—

Major-General A. Cuningham Robertson, C.B., 86 Great King Street.
William Denny, Bellfield, Dumbarton.
Dr Francis W. Moinet, F.R.C.P.E., 13 Alva Street.

Monday, 17th February 1879.

PROFESSOR KELLAND, President, in the Chair.

The following Communications were read:—

1. On some Physiological Results of Temperature Variation. By J. B. Haycraft, M.B., C.M. Communicated by Professor Turner.

2. On the Elasticity of the Walls of the Arteries and Veins. By Dr Roy. Communicated by Dr George W. Balfour.

3. Further Note on the Distribution of Temperature under the Ice in Linlithgow Loch. By Mr J. Y. Buchanan.

In continuation of the observations into the condition of the water of frozen lochs, which were communicated to the Society at the meeting of the 20th January 1879, I have been able to repeat the observations in Linlithgow Loch on two separate days, and also to visit Loch Lomond. The observations in Linlithgow Loch were made on the 25th January and 1st February, both times at the same spot, from which the Court House Flagstaff bore N. 150½° E., and the Rickles Island N. 63½° E., the depth being 48 feet. On the 25th January there was a diminution of pressure under the ice, so that when it was pierced the air rushed in with a roaring noise for about a minute, when it stopped, and the water rose in the hole. On the 1st February, on the other hand, the ice was cracking and resounding on all sides, and water rose at once in the hole when the ice was pierced, there being at the same time a considerable escape of air. These two stations have been numbered respectively 6 and 7; they are exactly in the same spot, a few yards distant from that of No. 4. The ice was very decidedly thicker than it had been.

Depth in Feet.	Temperature Fahr. at Station	
	No. 6.	No. 7.
3	36·00	36·00
6	36·60	36·80
12	37·35	37·50
18	37·35	37·80
21	...	37·80
24	37·50	38·15
30	37·90	38·30
36	38·45	39·00
42	39·80	40·70
45	...	42·00
Mud, 48	41·70	{ 42·00 42·05

From these observations we have the mean temperature of the 48 feet of water 37·83° on 25th January, and 38·28° on the 1st February. The heat required to produce this rise of temperature is very considerable, and would require the combustion of very nearly two tons of coal per acre.

It was shown that the mineral constituents of this water were insufficient to produce a lowering of its temperature of maximum density; it was, however, uncertain whether this effect might not have been produced by the substances which gave the water its peculiar odour. The actual temperature of maximum density of the water was accordingly compared with that of distilled water in the same piezometer, and no difference could be detected.

Hence it was evident that, before being completely frozen over, Linlithgow Loch must have been cooled down throughout to a mean temperature of certainly two degrees lower than that of its maximum density. As this conclusion was at variance with the generally accepted doctrine, it was necessary to test it by observations in another lake, and in one of undoubted purity. The result of observations made with this purpose in Loch Lomond on the 28th and 29th January was that the general lowering of temperature was even greater than in Linlithgow Loch, the mean temperature under the ice at a spot 51 feet deep being 34·05° F. Observations under the ice were made at four stations between Balloch and Luss, and several observations were made in the water off the edge of the ice,

where it terminated towards the upper and deeper reaches of the loch.

It results, from the discussion of these results, that the phenomena attending the freezing of a fresh-water lake may be stated as follows :—

First. Cooling down of the whole water to an approximately uniform temperature of 39·2° F.

Second. Local formation of ice generally as a shore fringe.

Third. Convection currents flowing at the surface from the ice to the middle of the loch, and at the bottom from the middle to the edge, caused by the disturbance of the equilibrium in consequence of the local occurrence of ice.

Fourth. Continuance of these currents for some time without appreciable diminution of strength, then gradual slackening of these currents as the temperature of the open water becomes lower, and the consequent difference of density on which their existence depends becomes less.

Fifth. The velocity of the water leaving the ice fringe and the facilities for losing heat at the surface, by radiation or convection, are so related that a portion of water leaving the ice fringe freezes before it can mix with the warmer water off shore.

Sixth. When condition fifth has been attained, rapid propagation of ice over the surface, and complete covering of the water with ice.

Seventh. Existence of the water under the exceptional condition of a uniform surface temperature, and consequent rapid equalising of differences of density in different parts. Did the loch consist of a mass of water enclosed in a basin which neither supplied nor removed heat, the condition of the water would alter only very slowly, owing to variation in thickness of the ice covering, and the gradual alteration of temperature of the water by conduction from the lower ice surface.

Hence the temperature of the bulk of the water under the ice of a frozen lake will tend to be uniform, and the uniform temperature to which it approximates will be determined by a number of local circumstances. It will lie between 39·2° and 32° F., and will depend on the shape and position of the loch as well as the geographical features of the surrounding land, and especially on the severity of the weather. The body of a loch will be cooled more

when it has been frozen by a moderate and comparatively long-continued frost than when the ice has been formed quickly by very severe frost. For the more severe the frost the sooner will it be able to overtake the water leaving the ice fringe; in other words, the stronger will be the current which it will be able to arrest, the greater the *head* which it will be able to stem But the head is caused by the higher temperature of the open water as compared with that under the ice. Hence the more severe the frost, the higher will be the temperature which it will be able to fix.

Eighth. Condition seventh is affected by heat supplied from the bottom. The amount due to the internal heat of the earth is certainly under present circumstances inappreciable. That due to decay of organic material in the water or at the bottom is also in all probability insensible in lochs of such purity as Loch Lomond, though it is of very serious importance in polluted lakes like Linlithgow.

Ninth. The change of the water of a lake affects the distribution of temperature after it is frozen. When the loch is entirely frozen over, the supply is delivered entirely at the surface, and therefore sensibly at a temperature of 32° F., which is also the temperature of the outflow. This water finds its way from its source to the outlet close under the ice, and lowers slightly the temperature of the water in the neighbourhood of the ice. The water which finds its way from the open part to the outlet does so along the bottom, and it is taken from the deep warm water of the open part in virtue of the convection currents at the edge of the ice. The temperature of the supply thus furnished to the frozen basin depends first on that of its source, namely, the deep water of the open part of the lake, and then on the configuration of the bottom, more especially on the maximum depth on the ridge separating the frozen basin from the open one. The shallower the water on the ridge the nearer will the deep water have to come to the surface in order to surmount it, and consequently the colder will it become.

The rising of warm water to the surface was very manifest at the passage between Inchtavannach and the Dumbartonshire shore of the loch.

Monday, 3d March 1879.

Professor MACLAGAN, Vice-President, in the Chair.

The following Communications were read:—

1. Heating and Ventilating of Churches and other Buildings: Report of a Series of Experiments made in a Hall in Upper Grove Place—Dimensions 50 × 25 feet, height about 20 feet; a Stove Chamber being outside at the south end, its roof about 8 feet in height; the only direct connection with the Hall being an opening in the mutual wall about 7 or 8 feet from the floor, and between 3 and 4 square feet dimensions. By Charles J. Henderson, Edinburgh. Communicated by Professor Jenkin.

Thermometers were placed throughout the hall, one on each of the four walls, 6 feet from the floor, the one on the south wall being a couple of feet below the inlet for the hot air. Three were placed along the centre of the roof, 2 feet or so under the roof. In the stove-chamber, first one and afterwards two stoves were placed, with double smoke-pipes before entering the chimney.

The trials were made for many weeks, and the tables on the two following pages give a fair representation of the results obtained in the warming of the hall; the effect on the four thermometers, 6 feet from the floor on all the four walls, being so remarkable as to induce my submitting these experiments to the notice of the Royal Society. Precisely as the heat, accumulated in the stove-room, entered the hall, each of these four thermometers rose in an equal degree, as shown in the tables, though the one at the north end was 50 feet off. The effect on the three roof thermometers is also shown in Table No. II. The stove-room had a doorway to outside, which during heating was only opened to a small extent.

It is worthy of notice the amount of heat obtained from the small quantity of coals consumed, which it is thought is the result of the peculiar construction of the stove smoke-pipes, each having four flanges; and the effect of placing two stoves in the chamber gives a very remarkable result as regards the fuel consumed, it being much the same as for one; showing the advantage, where much heat is required, of increasing the number and not the size of the stoves.

Table No. I.

Hall in Upper Grove Place, 50 × 25 Feet.

Time.	Outside.	Opening into Hall.	Six Feet from Floor.			
			North Wall.	South Wall.	East Wall.	West Wall.
	Deg.	Deg.	Deg.	Deg.	Deg.	Deg.
7 A.M. .	33	42	43	42	42	42
7.30 „ .	33	100	43	43	43	43
8 „ .	33	138	45	45	44	44
8.30 „ .	33	152	48	47	47	47
9 „ .	34	180	53	52	50	51
9.30 „ .	34	186	57	55	54	55
10 „ .	34	208	60	59	57	58
10.30 „ .	34	212	64	64	61	62
11 „ .	35	218	66	65	65	64
*11.30 „ .	35	224	66	67	66	66
12 „ .	36	228	67	68	67	67
	Ventilator in Hall opened and Stove-Room Door raised.					
12.30 P.M. .	36	142	62	63	63	62
1 „ .	37	136	60	61	61	60
1.30 „ .	37	110	59	61	60	59
2 „ .	37	104	59	60	59	59
2.30 „ .	38	90	58	60	59	59
3 „ .	38	84	58	60	58	58
3.30 „ .	38	76	58	60	58	58
4 „ .	38	70	57	59	57	57

Two Stoves, with Double Pipes. ¾ cwt. Coals used.

Time.	Outside.	Opening into Hall.	Six feet from Floor.			
			North Wall.	South Wall.	East Wall.	West Wall.
	Deg.	Deg.	Deg.	Deg.	Deg.	Deg.
6 A.M. .	33	42	42	42	42	42
6.30 „ .	33	76	42	42	42	43
7 „ .	33	90	43	43	43	43
7.30 „ .	34	100	44	45	44	44
8 „ .	34	112	45	46	45	45
8.30 „ .	34	132	47	48	46	47
9 „ .	35	138	50	51	49	49
9.30 „ .	35	144	53	53	51	51
10 „ .	35	146	54	55	52	52
10.30 „ .	35	148	55	56	54	53
11 „ .	35	149	56	57	55	54
11.30 „ .	35	154	56	57	56	55
12 „ .	36	156	57	58	57	57

Single Stove, with Double Pipes. ¾ cwt. Coals used.

* No more coals put on.

Table No. II.

Time.	Thermometer Outside.	Thermometer on Wall, 6 feet from floor.				South opening in Wall. Hot air enters.	South end of Ceiling.	Centre of Ceiling.	North end of Ceiling.	Front of Plat-form.
		North.	South.	East.	West.					
A.M.	Deg.	Deg.	Deg.	Deg.	Deg.	Deg.	Deg.	Deg.	Deg.	Deg.
6	44	52	52	52	53	53	53	53	52	52
6.30	45	53	53	52	53	102	76	59	59	56
7	45	56	56	54	54	147	96	72	70	62
7.30	45	60	60	59	59	182	126	90	86	71
8	46	65	65	62	62	202	136	97	93	77
8.30	47	69	69	67	68	228	164	110	106	85
* 9	48	71	72	70	70	230	166	118	112	89
9.30	*48*	*76*	*78*	*75*	*75*	*181*	*142*	*111*	*108*	*94*
10	*48*	*76*	*78*	*75*	*75*	*157*	*132*	*105*	*102*	*92*
10.30	*49*	*75*	*77*	*74*	*74*	*139*	*118*	*98*	*96*	*89*
11	*50*	*73*	*76*	*72*	*72*	*122*	*104*	*90*	*89*	*85*
11.30	*50*	*71*	*74*	*70*	*70*	*107*	*93*	*84*	*83*	*80*
12	*51*	*70*	*72*	*69*	*69*	*97*	*86*	*79*	*78*	*77*
P.M.										
12.30	*52*	*69*	*72*	*68*	*68*	*93*	*82*	*77*	*76*	*77*
1	*52*	*69*	*71*	*68*	*66*	*90*	*80*	*76*	*75*	*75*
1.30	*52*	*69*	*71*	*68*	*68*	*84*	*77*	*75*	*74*	*74*
2	*53*	*69*	*71*	*68*	*68*	*80*	*74*	*73*	*73*	*74*

Two Stoves, with Double Smoke-pipes, lighted at 6 A.M. Fire taken off 9 A.M. Hall Ventilators opened 1.30 P.M. Coals consumed, 70 lbs.

Note.—The figures in italics show the amount of heat got from the large surface of heated iron *after the fuel has been exhausted.*

Time.	Thermometer Outside.	Thermometer on Wall, 6 feet from Floor.				South opening in Wall. Hot air enters.	South end of Ceiling.	Centre of Ceiling.	North end of Ceiling.	Front of Plat-form.
		North.	South.	East.	West.					
A.M.	Deg.	Deg.	Deg.	Deg.	Deg.	Deg.	Deg.	Deg.	Deg.	Deg.
7	43	50	50	50	50	51	50	50	50	50
7.30	44	52	52	51	52	84	66	58	56	55
8	44	54	54	52	53	110	80	64	62	58
8.30	45	56	56	55	55	132	89	73	71	62
9	45	57	57	57	57	142	95	79	77	65
9.30	46	61	61	59	59	144	102	82	80	69
10	46	62	62	60	61	144	102	82	80	71
10.30	48	64	63	62	62	148	106	85	83	73
11	49	65	64	63	63	146	104	85	83	74
11.30	50	65	65	63	63	144	103	85	83	74
12	50	66	66	64	64	145	103	86	84	75

Single Stove with Double Pipes. Coals burned, 70 lbs. Stove lighted at 7 A.M.

* Fire taken off.

Various suggestions have occurred to me since these experiments were made for further improving the system, which I may shortly mention.

1. As to the stove-room, it ought to be lined in the inner portion with some radiating metal or non-conducting substance, and be divided into two parts, one containing the bodies of the stoves or pipes, the other for firing, &c., a doorway being left between the two for the admission of such amount of air as required. And further, as the quick removal of the heat given off from the metal of the stoves or pipes is of importance, it is proposed to introduce a fan in the inner division to be worked from the outer, and to admit as small a portion of cold air as may be practicable for carrying off the heat into the hall or church.

From the result of these experiments I have come to the conclusion that for warming and ventilating buildings a stove-room is required, but the best mode of raising heat therein is an open question.

For large buildings I believe steam-pipes placed in the chamber would be the cheapest, the boiler being either in the chamber or outside. The heat would be greater than from hot water, but this latter would answer very well, and, perhaps, on the whole, would be preferable, the amount of heat being regulated by the extent of pipes; and it cannot fail to occur to every one that the result obtained from the above experiments of the effect of *accumulated* heat discharged into a building in the manner described would in all respects be preferable to the present system of pipes distributed in the building itself. It is a mistake to introduce heat into a church or hall by dispersing it in pipes covered with gratings; the waste of heat must be very great, while, if the same amount were *accumulated* in a chamber, and sent on, as described above, it will be distributed in a way so perfectly suitable to what is required, as to cause wonder that so valuable a property of heat had not long ago been known.

Ventilation.

The stove-chamber is itself an efficient means for the introduction of fresh moderately warm air, by simply opening the outer door and allowing the air to pass over the heated stoves or pipes, aided, if required, by using the fan. But the more important matter still

remains of getting quit of the vitiated air produced in crowded assemblies. This also formed the subject of experiment in the hall by my having temporary wooden tubes, 12 × 6 inches wide, placed along the walls about 6 feet from the floor, and discharging outside the roof. These, in a crowded meeting, were found to be very efficient in carrying off the vitiated air, though occasionally a back-draught came down; but were the discharge into a cavity above the ceiling, or an archimedean can at the opening, the back-draught would be avoided.

I have perfect faith in the efficiency of these wall-tubes in carrying off the vitiated air, and may mention an attempt I made for a visible proof of this. I burnt brown paper to produce smoke. The smoke ascended only a few feet, and then spread out horizontally in a cloud, and when near any of the tubes it was drawn up.

Remarks.

In Table No. II. the course of the hot air on entering the hall is pretty well shown. The larger portion, of course, mounts towards the roof, along which it travels at somewhat different temperatures. Not so, however, below where the audience sits,—there the gradually-rising temperature is practically equal in all corners of the hall, and that without any appreciable difference in time between the effects on the several thermometers.

2. Chapters on the Mineralogy of Scotland. By Professor Heddle. Chapter VI. "Chloritic Minerals."

In this Chapter, Dr Heddle discussed the substances usually thrown together, under the term of Chloritic Minerals. He showed, by an extensive series of analyses, that they were to be divided into three groups—those which occurred in metamorphic rocks, in recent strata, and in volcanic rocks.

He proposed to confine the term Chloritic to the minerals which are found in metamorphic rocks, and to apply the term, the Saponites, to those which occur in volcanic rocks.

In Scotland, metamorphic rocks afforded the species Pennina, Ripidolite, Chlorite, and Chloritoid. The New Red Sandstone of Elgin yielded Glauconite. Volcanic rocks contained, plugging up

their steam holes, Delessite, Chlorophæite, Hullite, Saponite, and Celadonite.

Of these, Delessite seemed to be confined to igneous rocks of Old Red Sandstone age—Chlorophæite and Hullite to more recent volcanics; while the others occurred in rocks of both of these ages.

He doubted whether the so-called *Viridite* of petrologists had any claim to a specific title—possibly it might be either Delessite, Saponite, or Celadonite. He regarded it as most probably the last of these. No attempt had been made to show that it was not an already named substance; and until there was good appearance of this, it was in no way entitled to a place in mineral nomenclature.

Two new minerals, belonging to the first of these groups, were noticed as occurring in granite near Tongue in Sutherland, and in Rubislaw quarry.

3. On Deep-Sea Thermometers. By Mr J. Y. Buchanan.

For the purpose of observing the temperature of the waters below the surface in lakes and seas, two classes of thermometers have been used—namely, ordinary thermometers and self-registering ones. The earliest observations were made with the ordinary thermometer, and it was used in one of two ways—either it was sunk itself to the desired depth, and was so enveloped and protected by badly conducting material, that in bringing it up again through the layers of water of different temperature it had not time to alter its own temperature, or a quantity of the water at the desired depth was enclosed in a bucket of suitable construction and brought to the surface, and then immediately tested with the thermometer. Many very excellent and trustworthy observations exist which have been made in one of these ways. Our first knowledge of the temperature of the deep water of fresh-water lakes was obtained from the observations of Saussure on the lakes of Switzerland, made with a thermometer so padded and protected that it could be drawn up through 1000 feet of water of any temperature likely to be found in nature without sensibly altering its temperature. The self-acting bucket or sea-gauge was used at an earlier date in the determination of the temperature of the deep water of the ocean. The accuracy of the results obtained by this method depends greatly on the skill of the observer. In the case of Saussure and of Fischer and Brunner, the

results are clearly to be relied on implicitly. In the experiments with the sea bucket, also, excellent results have been obtained. The results obtained by both methods of experimenting will be the more accurate the more uniform the temperature of the water. The temperature, especially of the bottom water, has also frequently been determined by bringing up a quantity of the mud, and taking its temperature when it arrives on board. This method also gives very satisfactory results when a considerable quantity of mud is at disposal.

Self-Registering Thermometers.—By far the greatest number of observations has been made with self-registering thermometers of one form or another.

The first self-registering thermometer was made by Cavendish.* He constructed both a maximum and a minimum thermometer, and they were of the kind called by the French *à deversement*, *outflow* thermometers. In fact, his maximum thermometer is in every particular identical with that known in France as Walferdin's; his minimum is on the same principle, but has a U-formed stem instead of a straight one. The disadvantages of this form of thermometer are two—namely, the indications are not continuous, but by jerks, depending on the size of the mercury drops, and they require to be constantly set, the maximum at a higher and the minimum at a lower temperature than the one to be observed; they also require constant comparison with a standard. They are, therefore, not suitable for use where many observations have to be made expeditiously.

In the year 1782 Six† published a description of the combined maximum and minimum thermometer which bears his name, and which has since continued to assert its place among meteorological instruments as perhaps the best self-registering thermometer. The instrument is too well known to require particular description. It may, however, be noted that Six himself did not use a hair for a spring to keep his indices from falling down, but a fine glass thread soldered to the top of the index, and sticking up in a direction very slightly inclined to that of the length of the index, so that it pressed gently against the sides of the tube. The advantage of the glass

* Phil. Trans., 1758, l. p. 308.

† Phil. Trans., lxxii. p. 72.

over the hair is that it does not lose its elasticity; but, on the other hand, the index takes up more room, and requires a thermometer with a longer stem.

Maximum and minimum thermometers such as Cavendish's and Six's, when used for deep-sea exploration, show only the maximum and minimum temperatures to which they have been exposed in any one excursion, and a single observation with such a thermometer does not give us with certainty the temperature of the water at the depth to which it has been sunk. Hence, if we had a right to assume that the temperature of a sea or lake might vary in any conceivable way with the depth, these instruments would be valueless. We have, however, no right to make this assumption; we know, on the contrary, that in all seas whose surface is not exposed to a freezing temperature, the temperature of the water will as a rule diminish as the depth increases; that, therefore, the minimum temperature, as shown by the self-registering thermometer, will, in fact, be the temperature at the greatest depth attained by this thermometer. Hence, in such cases, this instrument is to be relied on, and more especially when *series* of temperatures are taken—that is, when the temperatures at different depths in the same locality are taken, so that the evidence of the decrease of temperature with increase of depth is rendered as strong as possible. In order to render an account of the state of any lake or sea as regards temperature, it is absolutely necessary to have such serial observations; hence, for such investigations, the maximum and minimum thermometer is not only perfectly trustworthy, but a most valuable and, indeed, indispensable instrument, for it has the great advantage that, as it is in the strictest sense *self*-registering, any number can be attached to the same line, and so at one haul the temperature can be observed at a number of different depths.

For isolated observations the thermometers just described are not so satisfactory, and a very great amount of ingenuity has been displayed in the invention of machines for registering the actual temperature of the water at any depth independently of that of the water above it. None of the instruments devised for this purpose have been strictly *self*-registering; they have all required some assistance from the observer, who, by various forms of mechanical appliance, brings about a catastrophe which leaves its mark on the

condition of the instrument. It is obvious that any control which an observer may have over an instrument separated from him by, it may be, three or four miles of cord, is very limited, and is, in fact, confined to his ability to move it towards or from him. By a simple mechanical contrivance this longitudinal motion may be made to produce one of rotation, and, in fact, the assistance afforded by the observer to the thermometer to enable it to register its own temperature consists in his turning it either upside down or through a whole circle when it has reached the desired depth. The first observer who made use of this device was Aimé. His working arrangement is described in Ann. Chim. Phys. 1843 [3] vii. p. 497. It is worked by a weight, which is allowed to slip down the line, and which then sets free the apparatus. His *thermomètre à bascule*, along with a number of ingenious modifications of existing forms, is described in the same journal, 1845 [3] xv. p. 5. It was unfortunately only after he was obliged to leave the Mediterranean, which had been the scene of his labours, that he invented the very elegant combination of thermometers by which he was enabled to ascertain the temperature at any depth, no matter what the intervening distribution might be. It is described in the memoir just cited. It consists of two outflow thermometers, so constructed that the one of them registers the sum of the rises of temperature, and the other the sum of the falls of temperature, to which it is exposed in any excursion. When they have reached the required depth they are inverted, and on their way back to the surface they register, as above described, the rises and falls of temperature to which they are exposed. If r be the sum of the rises of temperature, and f the sum of the falls, s the temperature of the surface, then the temperature at the depth where they were inverted will be $d = s + r - f$.

If they are allowed to register on the way down, and then inverted at the greatest depth, so as not to register on the way up, the effect will be precisely the same, though the functions of the thermometers will be reversed.

Beautiful and ingenious as Aimé's thermometers are, they have the disadvantages common to all outflow thermometers; they are neither simple enough nor handy enough for work involving many observations. The inverting thermometer, patented by Messrs

Negretti & Zambra, satisfies the conditions required of a thermometer for isolated observations as completely as can be hoped for. It is a mercurial thermometer; the bore of the stem is contracted to the smallest possible diameter at a point about an inch from the neck of the bulb. As long as the thermometer is standing vertically stem uppermost, the mercury is continuous in stem and bulb, but if it be inverted the mercury parts at the contraction, the portion in the stem falling down into the point. The stem is graduated from the point towards the bulb, and the temperature at the moment of inversion is read off by the height of the mercury in the end of the stem. This thermometer exists in two varieties, the one with a straight stem, which registers by simple inversion, the other with a U-formed stem, which requires to be turned completely round. The turning arrangement for the latter instrument is a somewhat elaborate and expensive instrument, but it answers its purpose. The inverting arrangement, supplied with the half-turn thermometer, is somewhat clumsy and unsatisfactory. The half-turn instrument, when fitted with a suitable inverting arrangement, is to be preferred to the others in all work at moderate depths. For ocean work it would probably be necessary to give up the protection of the whole stem, as it would be impossible to guarantee a tube, which can contain the whole instrument, against collapse when exposed to pressures of over 500 or 1000 fathoms of water. If the bulb and the twist on the stem were protected it would be quite sufficient.

Sources of Error in the Indications of various Thermometers.—When an ordinary thermometer, protected by badly-conducting envelopes, is used, it is obviously exposed to alteration of temperature by being pulled through warmer or colder water on its way to the surface. Whether any sensible error is likely to result from this cause must be determined in each particular case by experience. The more perfectly it resists change of temperature the longer it will take to assume the temperature of the water. Saussure left his thermometer down for twelve or fourteen hours for each observation, so that this method is now seldom used. Similarly, also, the method which depends on bringing up a sample of the water in a vessel fitted for the purpose, and taking its temperature with an ordinary thermometer when it reaches the surface, has been discontinued, for although it does not take much more time than would

be necessary for sending down a thermometer and bringing it up, it is impossible to bring up water from great depths in warm climates without sensible change of temperature.

In the case of outflow thermometers, the delicacy of the instrument is limited by the size of the mercury drops. In the inverting thermometers of Negretti and Zambra an error may arise from the difference of volume of the mercury in the stem at the temperature at which it was inverted, and at that at which it is read. In an extreme case this may amount to as much as 0·4° F.; it can, however, be allowed for.

In Six's instruments there is a possible error from looseness of the indices, in consequence of which they are apt to be shaken out of their places by any jarring of the line. Errors from this source can be avoided to a great extent by attaching the thermometer to the line by means of an elastic or india-rubber stop.

All the self-registering instruments are liable to error from the effects of pressure. The pressure inside a thermometer is never greater than that of the atmosphere when it was sealed up. It may, however, be exposed outside to a pressure of 500 or 600 atmospheres. The effect of this difference of pressure on the outside and inside of the glass envelope is to make it tend to collapse. The bulb of the thermometer is squeezed, and its volume in consequence diminished. The liquid which it contains is thereby forced into the stem, and its *apparent volume* is greater than it would have been had there been no excess of pressure on the outside of the instrument. The temperature of the instrument is measured by the apparent volume of the liquid which it contains; hence the effect of pressure is to raise the observed temperature above the true temperature. Parrot and Lenz,* in 1832, made a series of experiments on the effect of pressure on thermometers. They experimented at pressures up to 100 atmospheres, and observed differences between the apparent and the true temperatures of as much as 20° C. They found that for the same instrument the compression was simply proportional to the pressure. They used a thermometer as a manometer. After this date it was usual to attempt some kind of protection for self-registering thermometers. Those with straight stems, such as Walferdin's mini-

* Mem. del. Acad. Petersb. 6^{e} Série ii. p. 264.

mum, were sealed up in glass tubes, and so completely protected. Those whose stems were bent had to be enclosed in metal cases closed with a screw. This form of protection never answered well, as it was impossible to screw on the cover so tight that water under the great pressures met with at considerable depths would not find its way in. In order not to have to abandon the use of thermometers of the convenient form of Six's, the device of protecting the bulb only was hit upon, and it appears that the first thermometer of this kind was used by Captain Pullen on board H.M.S. *Cyclops*. The effect of pressure on the stem is quite insignificant, and under ordinary circumstances insensible. For, in nearly all seas where the surface temperature is over 40° F., the temperature of the water diminishes as the depth increases, and therefore it is the *minimum* leg which is used, and the effective part of it is that filled with spirit, which may have a length of at most three inches. The effect of pressure in diminishing the volume of a short piece of thermometer tubing must certainly be very small, but its actual value can only be determined by removing the bulb and taking the piece of the stem between the mercury and the neck of the bulb as the bulb of a new thermometer, and determining experimentally the effect of pressure on it. An approximation to the effect may be made by exposing the thermometer to various high pressures at known temperatures and observing the rise of the maximum index, then removing the bulb and calibrating the stem. Knowing, then, the ratio of the volume of this part of the minimum leg filled with spirit to the whole volume, from the bulb to the maximum index, it may be assumed that the compression will be in the same ratio. And this value will probably be greater than the real one, for the compression of the water produces of itself a certain rise of temperature, and consequently raises the maximum index. This can, however, be estimated either by comparison with a completely protected thermometer, or by bringing the minimum index also home on the mercury before raising the pressure. If, then, there has been a rise of temperature caused by compression, there will be a corresponding lowering of temperature on relieving the pressure. If the compression apparatus be allowed to stand, after the pressure is up, until it has dissipated the heat evolved by the compression, the

relief of pressure will cause a corresponding absorption of heat which will show itself in the position of the minimum index. Some experiments which I have made in this direction show a lowering of temperature of 0·3° F. for the relief of a pressure of $2\frac{1}{4}$ tons per square inch, the whole rise of the maximum index having been 1·8° F.

We may, I think, be quite certain that when the minimum leg is the one used and the temperature low, the error caused by the effect of pressure on the stem is inappreciable.

Cavendish, who invented the self-registering thermometer, foresaw also the most important of the uses to which it could be applied. Thus he suggests that the higher regions of the atmosphere might be investigated by attaching it to a kite—balloons not having been invented. With regard to deep-sea explorations, he says: "If instruments of the nature above described were to be used for finding the temper of the sea at great depths, some alteration would be necessary in the construction of them, principally on account of the great pressure of the water, the ill effect of which can, I believe, be prevented no other way than by leaving the tube open."

This was written in 1757, and it was not till 1762 that Canton proved that liquids are compressible. Cavendish therefore hoped that as the pressure would not produce distortion of the glass when the tube was open, it would have no visible effect on the apparent volume of the liquid. The device of leaving his thermometer open at the end was adopted by Aimé in some of his experiments, the effect of pressure on the apparent volume of the liquid being determined independently, and a correction applied accordingly. I devised and constructed a mercurial thermometer, or *piezometer*, on the same principle,* but my object in admitting the water pressure to the inside of the instrument was to utilise it in shifting the scale of the thermometer as the depths changed. The thing registered in such instruments is always the *apparent* volume of the liquid, and this varies with the temperature and the pressure. Hence the indications will represent the sum of the effects of change of temperature and of pressure. If from any independent source we know either of these, we can determine the other. In a sea of uniform temperature throughout its depth, the apparent volume of the liquid would

* Journal of the Chem. Soc. October 1878.

diminish as the pressure increased, and if the temperature increased with the depth, the apparent volume of the liquid would diminish at a slower rate; but it would be always possible to determine the true temperature as long as it did not increase at so great a rate as to dilate the liquid more than it was compressed by the increasing pressure. For the investigation of seas such as the Mediterranean this form of instrument is most valuable. The method of determining accurately both depth and temperature from the combined readings of a mercury and a water piezometer is explained in the paper communicated to the Chemical Society and above referred to.

In the great majority of cases the most convenient instrument to use is the form of Six's thermometer with protected bulb known as the Millar-Casella thermometer, with the following additions and improvements, which Mr Casella has applied to them at my suggestion:—The size of the instrument is increased so that the degrees are wider apart, a degree Fahrenheit on the minimum leg occupying about three millimetres of its length. Besides the scale of degrees which is attached on enamelled slips to the vulcanite at the sides of the stem, there is an arbitrary (millimetre) scale etched on the stem itself. The values of the divisions of this scale are ascertained by a careful comparison with a standard thermometer. It is thus possible to read with certainty to a quarter of a millimetre or a twelfth of a degree Fahrenheit. The errors due to the scale not being rigidly attached to the thermometer, and to the difficulty of determining the height of the index by reference to a scale at the side of instead of over it, are eliminated. Finally, by having the ordinary scale at the sides, the instrument can be used independently of the arbitrary scale, and, even where the arbitrary scale is principally relied on, the scale of degrees enables the observer to know very approximately the true temperature at the moment of observation without reference to tables, and, by noting on every occasion the reading on *both* scales, the chance of errors from misreading is greatly reduced.

The maximum leg, which is only rarely used, is of larger bore than the minimum one; the degrees, therefore, are closer, and the temperature of the instrument may rise as high as 100° F. without the index entering the terminal bulb. This is a detail of consider-

able practical importance, for it is impossible always to protect the thermometers when on deck from the direct rays of the sun, which would speedily disable the maximum side of the thermometer if its range were as limited as that of the minimum one.

It will be seen from what has been said that there is no one instrument which fulfils all conditions required of a perfect deep-sea thermometer. It is necessary, therefore, for the investigator to use his judgment in the selection of the instrument best suited for the particular case before him. In order to be prepared for possibly occurring cases, he should be provided with thermometers of (*a*) the Millar-Casella type, with the improvements just described; (*b*) the mercury piezometer; (*c*) the Negretti & Zambra inverting thermometer. It is well to have several of the first class (*a*), as any number of them can be attached to the line at different depths, and thus much time be saved. In my own practice I generally use four or five at a time. It is not advisable to exceed this number, as the loss in case of accident would be too heavy. Considering the distribution of temperature actually found in lakes and seas of warm and temperate regions, this is the most generally useful instrument when thorough investigation by means of *series* of observations is intended. In the particular and frequently occurring case of an enclosed sea containing a large mass of water showing no variation of temperature when tested by this instrument, it must be replaced by the mercury piezometer (*b*), which possesses the advantage that the position of the thermometric scale shifts along the stem according as the depth varies. Also any number of them can be used at the same time at different depths on the same line. In deep ocean soundings the combination of this instrument with the water piezometer for the determination of both depth and temperature independently of the length of the sounding line is invaluable for accurate work. The inverting thermometer of Messrs Negretti and Zambra (*c*) is the instrument most suitable for isolated observations. It is also of very great use for supplementing and controlling the observations with the other instruments, especially in the case of sea-lochs or fiords, where the temperature distribution is often much disturbed by the imperfect mixture of fresh with salt water.

For the successful and expeditious carrying out of deep-sea temperature observations, the investigator should be furnished with im-

proved Millar-Casella thermometers for the bulk of the work, and the mercury piezometer and the inverting thermometer for particular cases.

All the thermometers, of whatever type, should be carefully compared with a good standard and the results stated in terms of its scale.

4. Preliminary Note on a Crystalline Compound formed in Water containing Sulphuretted Hydrogen and Mercaptan in Solution. By J. Adrian Blaikie, B.Sc.

In the process of making mercaptan by collecting the distillate from a mixture of ethyl-sulphate of calcium and sulphydrate of potassium, along with water and mercaptan, a considerable quantity of crystalline substance was observed to collect in the receiver, and also towards the end of the condenser. The receiver having been placed in a freezing mixture, to condense as much mercaptan as possible, it was thought that the crystalline substance was ice, and the freezing mixture was removed. The crystals, however, continued to be formed, and even stopped up the end of the condenser, so that it was necessary to pour in hot water to melt them. In a few minutes they were again formed, not only in the receiver, but half way up the condensing tubes, through which water at about 2–3° C. was running. As it was evident that these crystals could not be ice, the conditions under which they were formed, and their composition, were subjected to investigation.

The solution of sulphydrate of potassium having been completely saturated with sulphuretted hydrogen at a low temperature, a considerable quantity of that gas was evolved before the formation of mercaptan took place. The crystals were therefore formed in an atmosphere of sulphuretted hydrogen, and as only water and mercaptan were present, could consist of water combined either with one or with both of the other substances.

By pouring a few drops of mercaptan into sulphuretted hydrogen water at 0° C., immediately a few crystals were formed. By passing sulphuretted hydrogen gas into water saturated with mercaptan, and with mercaptan floating on the surface, in a few minutes crystallisation took place, a large amount of sulphuretted hydrogen was absorbed,

and the water thickened into a soft crystalline mass. The quantity of the crystals depended on the amount of mercaptan if sulphuretted hydrogen were in excess, or on the amount of sulphuretted hydrogen if mercaptan were in excess.

On cooling water saturated with mercaptan no such crystalline appearance was observed. As is known from Wöhler's experiments (Annalen der Chemie und Pharmacie, xxxiii. 125), sulphuretted hydrogen only forms a hydrate at $-16°$ C., or under considerable pressure. From these results it is evident that both sulphuretted hydrogen and mercaptan are necessary for the formation of this crystalline compound.

The crystalline mass has much the same appearance as hydrate of chlorine, but is colourless. In the mother liquid the crystals exist for an indefinite time at any temperature below 3° C.; when dried they rapidly melt even at 0° C. Above 3° C. they melt in the mother liquid, with evolution of sulphuretted hydrogen, and formation of a thin layer of mercaptan above the water. Their specific gravity is greater than that of the mother liquid, which in turn is greater than that of ice. By allowing the crystals to stand in this mother liquid, in a corked flask cooled by means of ice-cold water, a crust forms on the surface, which appears to consist of hexagonal plates.

Newly formed crystals when observed under the microscope appear to be prisms, some long and fine, others short and thick, but as they rapidly melt, their form could not be more accurately observed. They dissolve rapidly in absolute alcohol at $-10°$ C., with evolution of a little sulphuretted hydrogen.

A mass of the crystals, when allowed to evaporate slowly, smell strongly of mercaptan, and deposit sulphur. Rapidly heated on platinum foil they suddenly melt, and a gas is given off which burns with a blue flame. The water left becomes milky with separation of sulphur. On further heat being applied the water is evaporated, and the sulphur burnt, without any residue. When dried between well-cooled filter paper, and dissolved in alcohol, with acetate of lead, a dark brown precipitate of sulphide of lead is thrown down, any precipitate of mercaptide of lead being hidden by the darker sulphide.

The presence of mercaptan was distinctly proved by com-

bustion. For combustion the crystals were collected on a funnel fitted with a platinum gauze cone, rapidly washed with ice-cold water, and dried on well-cooled filter paper. When dried as thoroughly as possible, they were rapidly placed in a weighed test tube, cooled in a freezing mixture, weighed, and inserted in an open combustion tube, the lower end of which was at a dull red heat. The combustion tube was filled with a mixture of three-fourths oxide of copper, and one-fourth chromate of lead, with a stream of oxygen passing through it.

The following are the results of analysis:—

I.	·8515 gr.	gave	·8355 H_2O	and	·0525 CO_2
II.	·7655	„	·7530	„	·0380 „
III.	·6820	„	·6620	„	·0365 „

The percentage of carbon is	(1) 1·68 (2) 1·35 (3) 1·46	equivalent to per cent. of mercaptan	(1) 4·33 (2) 3·49 (3) 3·77

The excess of carbon in No. I. is caused probably by the difficulty in obtaining a perfectly dry substance, free from adhering mercaptan.

Direct estimations of sulphur have not as yet proved satisfactory; in some experiments mercaptan was oxidised along with sulphuretted hydrogen, in other cases it was not. It is hoped that shortly a method may be obtained for the more accurate estimation of sulphur in this substance.

From the above results it would appear that the chief constituent of this crystalline compound is water (not less than 90 per cent.), combined with a small quantity of mercaptan and sulphuretted hydrogen.

With sulphide of ethyl, sulphuretted hydrogen, and water, no crystalline compound is formed at 0° C. With sulphide of amyl or with sulphydrate of amyl the results were also negative.

With sulphide of methyl the formation of a crystalline compound is obtained with ease. To a small quantity of water at 2° C. a little pure sulphide of methyl was added, and sulphuretted hydrogen passed in. In a very few minutes crystallisation commenced, and sulphuretted hydrogen was absorbed. These crystals are more stable than those of mercaptan, and it is the writer's intention to study this compound in order to discover whether it has a definite composition.

5. Laboratory Notes. By Professor Tait.

(1.) Measurements of the Electromotive Force of the Gramme Machine at Different Speeds.

The following measurements were made by means of a Gramme machine, recently procured for the University. I desired to make use of it, not only for electric light, but for electrolysis, the exciting of electromagnets, and various other purposes for which we have hitherto used from 4 to 40 or so Bunsen cells. I therefore arranged the driving-gear so that with the same motor (a $3\frac{1}{2}$ h.p. gas-engine) it was easy to use either of three speeds. These are, approximately, 800, 533, and 320 turns per minute. The electromotive force varies, of course, not only with the speed but with the resistance of the whole circuit—falling off at first rapidly and then more slowly for any one speed, as the resistance is increased. As I had no means of measuring the speed *directly*, I was somewhat puzzled at first to find the electromotive force at any one speed rise to a maximum, and then rapidly fall off as the whole resistance was gradually diminished. But I soon found that this was due in great part to the slipping of the driving-belts (though they were very tight), whenever the intensity of the current exceeded a certain amount. A liberal use of rosin almost removed this anomaly, though there is reason to believe there is still considerable slipping.

The following table gives the average of a number of experiments which accord fairly with one another. The resistance of the conductor of the Gramme machine is about 1·16 B. A. units. For the added resistance I used coils of stout covered copper wire which were in the laboratory, having resistances 0·054, 1·844, and 3·63, respectively. The first was always in circuit, and a portion of it, of resistance 0·0015, was introduced into the circuit of a galvanometer having a resistance 23. The deflections of the galvanometer were observed with the first coil alone in the circuit of the Gramme, then with the addition of the second or third, and finally with all the coils.

The explosions in the gas-engine occur only at every *second* stroke of the piston. This and other causes render the driving power not absolutely steady, but the *average* deflection of the galvanometer was very easily observed.

From the graphic representation of the results the following numbers were taken :—

Nominal Speed.	Whole Resistance.	Electromotive Force in terms of a Bunsen cell.
800	1·5	38*
...	3·	38
...	4·5	36
...	6	31
533	1·5	24
...	3·	23
...	4·5	17·5
...	6·	9·
320	1·5	13
...	3·	5
...	4·5	2·5
...	6	2·

Next, instead of the second or third coils above mentioned, a Duboscq's lamp was included in the circuit, the other arrangements being as before, and the speed being 800 nominal. The deflection corresponded to an electromotive force of about 39 Bunsen cells, and a resistance of 2·66. As the lamp itself was sometimes found to have a resistance of as much as 0·6, and as the carbons have a resistance of from 0·115 to 0·045, per 4 inches, it appears that, approximately, the resistance of the electric arc, under these conditions, is at least 0·8.

Subsequent experiments, in which the lamp was not used, gave resistances varying from 0·75 to 1·2, according to the length of the arc —and when a little sodium was introduced, it fell to 0·25. These estimates, of course, include the effect due to heating and pointing the carbons.

The want of accurate speed determinations, of course, deprives these results of scientific value, but they are very useful as an expression of the electromotive force practically to be obtained from the Gramme machine under different circumstances of its ordinary working,—showing, as they do, what adjustments to make for the purposes of a particular experiment.

* This particular number must be over-estimated, for about 5 h.p. is required to maintain an electromotive force of 38 Bunsens in a resistance 1·5.

The very rapid increase of electromotive force with diminished resistance at the lowest speed, seems to show that the speed is very considerably overrated when stated as 800 or 533, with the resistance between 1 and 2 B. A. units. I hope soon to have the means of accurately measuring the speed realised, and shall then repeat these experiments for a scientific, and not a mere practical purpose.

(2.) On the Law of Extension of India-rubber at Different Temperatures.

To fill the vacancies in Foreign Honorary Fellowships caused by the deaths of Claude Bernard, Elias Magnus Fries, Henri Victor Regnault, Angelo Secchi, the following Gentlemen were elected:—

Frank Cornelius Donders, Utrecht.
Asa Gray, Cambridge, U.S.
Jules Janssen, Paris.
Johann Benedict Listing, Gottingen.

The following Gentlemen were duly elected Fellows of the Society:—

Thomas H. Cockburn Hood, F.G.S., Junior Carlton Club, Pall Mall.
Thomas Gilray, M.A., 6 Carlung Place, Edinburgh.
Alex. Bennett M'Grigor, LL.D., 19 Woodside Terrace, Glasgow.
James Blaikie, M.A., 14 Viewforth Place, Edinburgh.

Monday, 17th March 1879.

Professor KELLAND, President, in the Chair.

The following Communications were read:—

1. On Gravitational Oscillations of Rotating Water. By Sir William Thomson.

(*Abstract.*)

This is really Laplace's subject in his Dynamical Theory of the Tides; where it is dealt with in its utmost generality except one important restriction,—the motion of each particle to be infinitely nearly horizontal, and the velocity to be always equal for all par-

ticles in the same vertical. This implies that the greatest depth must be small in comparison with the distance that has to be travelled to find the deviation from levelness of the water-surface altered by a sensible fraction of its maximum amount. In the present short communication I adopt this restriction; and farther, instead of supposing the water to cover the whole or a large part of the surface of a solid spheroid as does Laplace, I take the simpler problem of an area of water so small that the equilibrium-figure of its surface is not sensibly curved. Imagine a basin of water of any shape, and of depth, not necessarily uniform, but, at greatest, small in comparison with the least diameter. Let this basin and the water in it rotate round a vertical axis with angular velocity ω so small that the greatest equilibrium slope due to it may be a small fraction of the radian: in other words, the angular velocity must be small in comparison with $\sqrt{\frac{g}{\frac{1}{2}A}}$, where g denotes gravity, and A the greatest diameter of the basin. The equations of motion are

$$\left.\begin{aligned}\frac{du}{dt} - 2\omega v &= -\frac{1}{\varrho}\frac{dp}{dx}\\ \frac{dv}{dt} + 2\omega u &= -\frac{1}{\varrho}\frac{dp}{dy}\end{aligned}\right\} \quad . \quad . \quad . \quad . \quad . \quad (1)$$

where u and v are the component velocities of any point of the fluid in the vertical column through the point (xy), relatively to horizontal axes Ox Oy revolving with the basin; p the pressure at any point x, y, z, of this column; and ϱ the uniform density of the liquid. The terms $\omega^2 x$, $\omega^2 y$, which appear in ordinary dynamical equations referred to rotating axes represent components of centrifugal force, and therefore do not appear in these equations. Let now D be the mean depth and $D+h$ the actual depth at any time t in the position (xy). The "equation of continuity" is

$$\frac{d(Du)}{dx} + \frac{d(Dv)}{dy} = -\frac{dh}{dt} \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

Lastly, by the condition that the pressure at the free surface is

constant, and that the difference of pressures at any two points in the fluid is equal to $g\times$ difference of levels, we have

$$\left.\begin{aligned}\frac{dp}{dx}&=g\varrho\frac{dh}{dx}\\ \frac{dp}{dy}&=g\varrho\frac{dh}{dy}\end{aligned}\right\} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

Hence for the case of gravitational oscillations (1) become

$$\left.\begin{aligned}\frac{du}{dt}-2\omega v&=-g\frac{dh}{dx}\\ \frac{dv}{dt}+2\omega u&=-g\frac{dh}{dy}\end{aligned}\right\} \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

From (1) or (4) we find by differentiation, &c.

$$\frac{d}{dt}\left(\frac{dv}{dx}-\frac{du}{dy}\right)+2\omega\left(\frac{du}{dx}+\frac{dv}{dy}\right)=0 \quad . \quad . \quad . \quad (5)$$

which is the equation of vortex motion in the circumstances.

These equations reduced to polar coordinates, with the following notation,—

$$x=r\cos\theta\,,\ y=r\sin\theta$$
$$u=\zeta\cos\theta\tau\quad\sin\theta\,,\ v=\zeta\sin\theta+\tau\cos\theta\,,$$

become

$$\frac{\mathrm{D}\zeta}{r}+\frac{d(\mathrm{D}\zeta)}{dr}+\frac{d(\mathrm{D}\tau)}{rd\theta}=-\frac{dh}{dt} \quad . \quad . \quad . \quad . \quad . \quad (2')$$

$$\left.\begin{aligned}\frac{d\zeta}{dt}-2\omega\tau&=-g\frac{dh}{d\zeta}\\ \frac{d\tau}{dt}+2\omega\zeta&=-g\frac{dh}{rd\theta}\end{aligned}\right\} \quad . \quad . \quad . \quad . \quad . \quad . \quad (4')$$

$$\frac{d}{dt}\left(\frac{\tau}{r}+\frac{d\tau}{dr}-\frac{d\zeta}{rd\theta}\right)+2\omega\left(\frac{\zeta}{r}+\frac{d\zeta}{dr}+\frac{d\tau}{rd\theta}\right)=0 \quad . \quad (5')$$

In these equations D may be any function of the coordinates. Cases of special interest in connection with Laplace's tidal equations are had by supposing D to be a function of r alone. For the present,

however, we shall suppose D to be constant. Then (2) used in (5) or (2′) in (5′) gives after integration with respect to t

$$\frac{dv}{dx}-\frac{du}{dy}=2\omega\frac{h}{\mathrm{D}} \qquad \ldots \ldots \qquad (6)$$

or in polar coordinates

$$\frac{\tau}{r}+\frac{d\tau}{dr}-\frac{d\zeta}{rd\theta}=2\omega\frac{h}{\mathrm{D}} \qquad \ldots \ldots \qquad (6')$$

These equations (6) (6′) are instructive and convenient though they contain nothing more than is contained in (2) or (2′), and (4) or (4′).

Separating u and v in (4), or ζ and τ in (4′), we find

$$\left.\begin{aligned}&\frac{d^2u}{dt^2}+4\omega^2u=-g\left(\frac{d}{dt}\frac{dh}{dx}+2\omega\frac{dh}{dy}\right)\\ \text{and}\quad &\\ &\frac{d^2v}{dt^2}+4\omega^2v=g\left(2\omega\frac{dh}{dx}-\frac{d}{dt}\frac{dh}{dy}\right)\end{aligned}\right\} \qquad \ldots \qquad (7)$$

or in polar coordinates

$$\left.\begin{aligned}&\frac{d^2\zeta}{dt^2}+4\omega^2\zeta=-g\left(\frac{d}{dt}\frac{dh}{dr}+2\omega\frac{dh}{rd\theta}\right)\\ &\frac{d^2\tau}{dt^2}+4\omega^2\tau=g\left(2\omega\frac{dh}{dr}-\frac{d}{dt}\frac{dh}{rd\theta}\right)\end{aligned}\right\} \qquad \ldots \qquad (7')$$

Using (7) (7′), in (2) (2′), with D constant, or in (6) (6′) we find—

$$g\mathrm{D}\left(\frac{d^2h}{dx^2}+\frac{d^2h}{dy^2}\right)=\frac{d^2h}{dt^2}+4\omega^2h \qquad \ldots \qquad (8)$$

and

$$g\mathrm{D}\left(\frac{d^2h}{dr^2}+\frac{1}{r}\frac{dh}{dr}+\frac{d^2h}{rd\theta^2}\right)=\frac{d^2h}{dt^2}+4\omega^2h \qquad \ldots \qquad (8')$$

It is to be remarked that (8) and (8′) are satisfied with u or v substituted for h.

I. Solutions for Rectangular Coordinates.

The general tpye-solution of (8) is $h=\epsilon^{\alpha x}\epsilon^{\beta y}\epsilon^{\gamma t}$ where α, β, γ, are connected by the equation

$$\alpha^2+\beta^2=\frac{\gamma^2+4\omega^2}{g\mathrm{D}} \qquad \ldots \ldots \qquad (9)$$

For waves or oscillations we must have $\gamma=\sigma\sqrt{-1}$ where σ is real.

I*a*. *Nodal Tesseral Oscillations.*

For nodal oscillations of the tesseral type we must have $\alpha = m\sqrt{-1}$, $\beta = n\sqrt{-1}$ where m and n are real, and by putting together properly the imaginary constituents we find

$$h = \mathrm{C} \frac{\sin}{\cos} \sigma t \frac{\sin}{\cos} mx \frac{\sin}{\cos} ny \quad . \quad . \quad . \quad . \quad (10),$$

where m, n, σ are connected by the equation

$$m^2 + n^2 = \frac{\sigma^2 - 4\omega^2}{g\mathrm{D}} \quad . \quad . \quad . \quad . \quad . \quad . \quad (11).$$

Finding the corresponding values of u and v, we see what the boundary conditions must be to allow these tesseral oscillations to exist in a sea of any shape. No bounding line can be drawn at every part of which the horizontal component velocity perpendicular to it is zero. Therefore to produce or permit oscillations of the simple harmonic type in respect to form, water must be forced in and drawn out alternately all round the boundary, or those parts of it (if not all) for which the horizontal component perpendicular to it is not zero. Hence the oscillations of water in a rotating rectangular trough are not of the simple harmonic type in respect to form, and the problem of finding them remains unsolved.

If $\omega = 0$, we fall on the well-known solution for waves in a non-rotating trough, which are of the simple harmonic type.

I*b*. *Waves or Oscillations in an endless Canal with straight parallel sides.*

For waves in a canal parallel to x, the solution is

$$h = \mathrm{H}\epsilon^{-ly} \cos(mx - \sigma t) \quad . \quad . \quad . \quad . \quad . \quad (12),$$

where l, m, σ satisfy the equation

$$m^2 - l^2 = \frac{\sigma^2 - 4\omega^2}{g\mathrm{D}} \quad . \quad . \quad . \quad . \quad . \quad . \quad (13),$$

in virtue of (9) or (11).

Using these in (7) we find that v vanishes throughout if we make

$$l=\frac{2\omega m}{\sigma} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (14);$$

and with this value for l in (12), we find, by (7),

$$u=\mathrm{H}\frac{gm}{\sigma}\epsilon^{-ly}\cos(mx-\sigma t) \quad . \quad . \quad . \quad (15):$$

and using (14) and (13) we find

$$m^2=\frac{\sigma^2}{g\mathrm{D}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (16),$$

from which we infer that the velocity of propagation of waves is the same for the same period as in a fixed canal. Thus the influence of rotation is confined to the effect of the factor $\epsilon^{-2\omega m/\sigma . y}$. Many interesting results follow from the interpretation of this factor with different particular suppositions as to the relation between the period of the oscillation $\left(\frac{2\pi}{\sigma}\right)$, the period of the rotation $\left(\frac{2\pi}{\omega}\right)$, and the time required to travel at the velocity $\frac{\sigma}{m}$ across the canal. The more approximately nodal character of the tides on the north coast of the English Channel than on the south or French coast, and of the tides on the west or Irish side of the Irish Channel than on the east or English side, is probably to be accounted for on the principle represented by this factor, taken into account along with frictional resistance, in virtue of which the tides of the English Channel may be roughly represented by more powerful waves travelling from west to east, combined with less powerful waves travelling from east to west, and those of the southern part of the Irish Channel by more powerful waves travelling from south to north combined with less powerful waves travelling from north to south. The problem of standing oscillations in an endless rotating canal is solved by the following equations—

$$\left.\begin{aligned} h&=\mathrm{H}\ \{\epsilon^{-ly}\cos(mx-\sigma t)-\epsilon^{ly}(\cos mx+\sigma t)\} \\ u&=\mathrm{H}\frac{gm}{\sigma}\{\epsilon^{-ly}\cos(mx-\sigma t)+\epsilon^{ly}\cos(mx-\sigma t)\} \\ v&=0 \end{aligned}\right\} \quad . \quad (17)$$

If we give ends to the canal we fall upon the unsolved problem referred to above of tesseral oscillations. If instead of being rigorously straight we suppose the canal to be circular and endless, provided the breadth of the canal to be small in comparison with the radius of the circle, the solution (17) still holds. In this case, if c denote the circumference of the canal, we must have $m=\frac{2i\pi}{c}$, where i is an integer.

II. Oscillations and Waves in Circular Basin (Polar Coordinates).

Let

$$h=\mathrm{P}\cos(i\theta-\sigma t) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (18)$$

be the solution for height, where P is a function of r. By (8′) P must satisfy the equation

$$\frac{d^2\mathrm{P}}{dr^2}+\frac{1}{r}\frac{d\mathrm{P}}{dr}-\frac{i^2\mathrm{P}}{r^2}+\frac{\sigma^2-4\omega^2}{g\mathrm{D}}\mathrm{P}=0 \quad . \quad . \quad . \quad . \quad . \quad (19)$$

and by (7′) we find

$$\left.\begin{aligned} \zeta&=\frac{g}{\sigma^2-4\omega^2}\sin(i\theta-\sigma t)\left(\sigma\frac{d\mathrm{P}}{dr}-2\omega i\,\frac{\mathrm{P}}{r}\right)\\ \tau&=\frac{-g}{\sigma^2-4\omega^2}\cos(i\theta-\sigma t)\left(2\omega\frac{d\mathrm{P}}{dr}-\sigma i\,\frac{\mathrm{P}}{r}\right)\end{aligned}\right\} \quad . \quad . \quad . \quad (20)$$

This is the solution for water in a circular basin, with or without a central circular island. Let a be the radius of the basin, and if there be a central island let a' be its radius. The boundary conditions to be fulfilled are $\zeta=0$, when $r=a$, and when $r=a'$. The ratio of one to the other of the two constants of integration of (19), and the speed σ of the oscillation, are the two unknown quantities to be found by these two equations. The ratio of the constants is immediately eliminated, and the result is a transcendental equation for σ. There is no difficulty, only a little labour, in thus finding as many as we please of the fundamental modes, and working out the whole motion of the system for each. The roots of this equation, which are found to be all real by the Fourier-Sturm-Liouville-theory,

are the speeds * of the successive fundamental modes, corresponding to the different circular nodal subdivisions of the i diametral divisions implied by the assumed value of i. Thus, by giving to i the successive values 0, 1, 2, 3, &c., and solving the transcendental equation so found for each, we find all the fundamental modes of vibration of the mass of matter in the supposed circumstances.

If there is no central island, the solution of (19) which must be taken, is that for which P and its differential coefficients are all finite when $r=0$. Hence P is what is called a Bessel's function of the first kind and of order i; and according to the established notation † we have

$$\mathrm{P}=\mathrm{J}_i\left(r\sqrt{\frac{\sigma^2-\omega^2}{g\mathrm{D}}}\right) \quad . \quad . \quad . \quad (21)$$

The solution found above for an endless circular canal is fallen upon by giving a very great value to i. Thus, if we put $\frac{2\pi r}{i}=\lambda$ so that λ may denote wave-length, we have $\frac{i}{r}=\frac{2\pi}{\lambda}$, which will now be the m of former notation. We must now neglect the term $\frac{1}{r}\frac{dh}{dr}$ in (19), and thus the differential equation becomes

$$\frac{d^2h}{dr^2}+\left(\frac{\sigma^2-4\omega^2}{g\mathrm{D}}-m^2\right)h=0\,,$$

or

$$\frac{d^2h}{dr^2}-l^2h=0 \quad . \quad . \quad . \quad . \quad (22),$$

where l^2 denotes $m^2-\frac{\sigma^2-4\omega^2}{g\mathrm{D}}$. A solution of this equation is $h=c\epsilon^{-ly}$ where $y=a-r$, and using this in (20) above, we find $\zeta=\frac{-g}{\sigma^2-4\omega^2}\,\mathrm{C}\sin(mx-\sigma t)(\sigma l-2\omega m)\epsilon^{-ly}$, where $mx=i\theta$. Hence, to make $\zeta=0$ at each boundary, we have $\sigma l=2\omega m$, which makes

* In the last two or three tidal reports of the British Association the word "speed," in reference to a simple harmonic function, has been used to designate the angular velocity of a body moving in a circle in the same period. Thus, if T be the period $\frac{2\pi}{\mathrm{T}}$ is the speed; *vice versa*, if σ be the speed $\frac{2\pi}{\sigma}$ is the period.

† Neumann, "Theorie der Bessel'schen Functionen" (Leipzig, 1867), § 5; and Lommel, "Studien über die Bessel'schen Functionem" (Leipzig 1868), § 29.

$\zeta=0$, not only at the boundaries, but throughout the space for which the approximate equation (22) is sufficiently nearly true. And, putting for l^2 its value above, we have

$$4\omega^2 m^2 = \sigma^2\left(m^2 - \frac{\sigma^2 - 4\omega^2}{g\mathrm{D}}\right);$$

whence

$$m^2 = \frac{\sigma^2}{g\mathrm{D}},$$

which agrees with (16) above.

I hope in a future communication to the Royal Society to go in detail into particular cases, and to give details of the solutions at present indicated, some of which present great interest in relation to tidal theory, and also in relation to the abstract theory of vortex motion. The characteristic differences between cases in which σ is greater than 2ω, or less than 2ω, are remarkably interesting, and of great importance in respect to the theory of diurnal tides in the Mediterranean, or other more or less nearly closed seas in middle latitudes, and of the lunar fortnightly tide of the whole ocean. It is to be remarked that the preceding theory is applicable to waves or vibrations in any narrow lake or portion of the sea covering not more than a few degrees of the earth's surface, if for ω we take the component of the earth's angular velocity round a vertical through the locality, that is to say, $\omega=\gamma \sin l$, where γ denotes the earth's angular velocity, and l the latitude.

2. On the Effects of Chloroform, Ethidene Dichloride, and Ether on Blood-Pressure. By Joseph Coats, M.D., William Ramsay, Ph.D., and John G. M'Kendrick, M.D., the University of Glasgow. Communicated by Professor M'Kendrick.

Abstract.

Dr Coats stated that this communication referred to part of an investigation on the physiological action of anæsthetics, undertaken, at the request of the British Medical Association, by Dr Ramsay, Dr M'Kendrick, and himself. After describing the method of obtaining accurate tracings of variations in blood-pressure by means of a kymograph, he stated that the facts obtained from these re-

searches seemed to the Committee to warrant the following conclusions :—

1. Both chloroform and ethidene administered to animals have a decided effect in reducing the blood-pressure, while ether has no appreciable effect of this kind.

2. Chloroform reduces the pressure much more rapidly and to a greater extent than ethidene.

3. Chloroform has sometimes an unexpected and apparently capricious effect on the heart's action, the pressure being reduced with great rapidity almost to *nil*, while the pulsations are greatly retarded or even stopped. The occurrence of these sudden and unlooked-for effects on the heart's action seems to be a source of serious danger to life, all the more that in two instances they occurred more than a minute after chloroform had ceased to be administered, and after the recovery of the blood-pressure.

4. Ethidene reduces the blood-pressure by regular gradations and not, so far as observed, by these sudden and unexpected depressions.

5. Chloroform may cause death in dogs either by primarily paralysing the heart or the respiratory mechanism. The variations in this respect seem to depend to some extent on individual peculiarities of the animals; in some the cardiac centrés are more readily affected, in others the respiratory. But peculiarities in the condition of the same animal very probably have some effect in determining the vulnerability of these two centres respectively, and they may both fail simultaneously.

6. In most cases respiration stops before the heart's action, but there was one instance in which respiration continued while the heart had stopped, and only failed a considerable number of seconds after the heart had resumed.

7. The use of artificial respiration was very effective in restoring animals in danger of dying from the influence of chloroform. In one instance its prolonged use produced recovery even when the heart had ceased beating for a considerable time.

8. Under the use of ethidene there was on no single occasion an absolute cessation either of the heart's action or of respiration, although they were sometimes very much reduced. It can therefore be said that, though not free from danger on the side of the

heart and respiration, this agent is, in a very high degree, safer than chloroform.

9. These results confirm and amplify those stated in a previous report, to the effect that ethidene does not compromise the heart as does chloroform. By the method of experimentation then employed, the effect on the blood-pressure could not be determined, and altogether the results here obtained are more exact and unequivocal.

3. Experiments with Rotating Discs. By Mr John Aitken. Communicated by Professor M'Kendrick.

4. General Theorems on Determinants. By Thomas Muir, M.A.

5. Preliminary Note on Alternants. By Thomas Muir, M.A.

(*Abstract.*)

When the elements of the first row of a determinant are all positive integral powers of one quantity, the elements of the second the like positive integral powers of another quantity, and so on, the determinant is called an Alternant; for example,

$$\begin{vmatrix} a^m & a^n & a^p \\ b^m & b^n & b^p \\ c^m & c^n & c^p \end{vmatrix}.$$

Every alternant of the n^{th} degree is evidently a function of n variables, viz., the n quantities whose powers are the elements. To interchange two of these variables would be the same as to interchange two of the rows of the determinant, and therefore would have the effect of merely changing the sign of the function. A function having this property, and therefore closely resembling a symmetric function, Cauchy called a symmetric function also, distinguishing the two kinds as *alternating* and *permanent*. The narrower meaning of symmetric having, however, been adhered to, the other kind of function, viz., that above exemplified, has been known as simply an *alternating function*, and hence Sylvester's word *alternant*.

Now it is well known that the alternant whose indices are in order 0, 1, 2, 3, ... is equal to the difference-product of its variables. In regard to every other alternant it is evident that it must contain the said difference-product as a factor, but what the co-factor should be is not so readily seen. In particular cases, doubtless, it can be found without much difficulty, but a general method of obtaining it has hitherto been a desideratum. Such a general method the author has discovered along with a number of less important results, bearing on the same special form of determinant.

Monday, 7th April 1879.

Sir ALEXANDER GRANT, Bart., Vice-President, in the Chair.

1. Professor Geddes's Theory of the "Iliad." By Professor Blackie.

(*Abstract.*)

Professor Blackie, after paying a high compliment to the erudition, ingenuity, and fine taste of the Aberdeen Hellenist, proceeded to give reasons why, in his opinion, the theory now broached, to the effect that certain books of the "Iliad" were composed by the author of the "Odyssey," which author is to be considered as the real Homer, though not destitute of a certain plausibility, is untenable. The reasons were—(1.) The character of the minstrel as distinguished from the literary epos warrants the presumption that any small diversity in certain secondary characteristics of different sections of the poem, as we now have it, is a legitimate proof, not of diversity of authorship, but only of diversity of materials collected from different sources. (2.) The manner in which the minstrel epos was originally circulated, not as a separate literary composition to be read and studied, but as a sequence of easily separable cantos to be handed about and sung separately, rendered it, even when wrought into a finished artistic whole by the genius of a great singer, peculiarly liable to interpolations and variations of various kinds, which form no legitimate ground of induction with regard to the character

or attitude of the original composer. (3.) Not a few of the most prominent differential features emphasized by Professor Geddes are to be looked rather as the two sides of one rich mind than as the diverse workmanship of two different minds. A great poet will be as tender on one occasion as he is fierce on another, and Goethe is not the less author of "Torquato Tasso" because he is the author of "Faust." (4.) Not the least objection to the books exsected by Mr Grote, and appropriated by Professor Geddes, being attributed to the author of the "Odyssey," is the fact that some of these books are at once the most poetically impressive and the most fully charged with the fervour peculiar to the "Iliad," and, if they are not absolutely necessary to what Mr Grote calls the logical sequence of the poem, do certainly contribute most largely to its effect as a work of art. (5.) Some of the differential features dwelt on by the Aberdeen Professor are either too slight, too sparse, and too equivocal to warrant any sure induction, or are explained most naturally by the character and tone of the poem, and the nature of the subject. In the quiet books of the "Iliad" some things would naturally occur that are more kindred to the gentle tone of the "Odyssey," than the fervid and somewhat fierce tone and contents of those books of the "Iliad" where Achilles is the dominant figure. (6.) Lastly, the theory of development in moral and religious matters applied by Professor Geddes to the "Odyssey," and what he calls the Odyssean books of the "Iliad," Professor Blackie felt himself compelled flatly to deny. Jove is in every respect as stern and just a moral governor of the world in the "Iliad" as in the "Odyssey;" and the haughtiness of Agamemnon meets with its retribution, as publicly and as prominently in the one poem, as does the insolence of the Suitors in the other. In the "Iliad," Zeus is the steward of national war—ταμιας πολέμοιο; in the "Odyssey" the avenger of domestic wrong (ξένιος); but in both poems he is equally moral in great cosmical matters, and equally immoral, as it strikes us, in certain small personal matters. There are no palæozoic and neozoic periods of theological belief to warrant the assumption of successive stages of moral development in different portions of the Homeric poems.

At the close of Professor Blackie's paper, Professor Campbell, St Andrews, remarked that before reading the book of Professor Geddes he looked upon Grote's theory with some doubt and suspicion, but

after reading the book his opinion was modified. He thought Professor Geddes had strengthened the case for Grote's theory, though not to the extent of proving an affirmative.

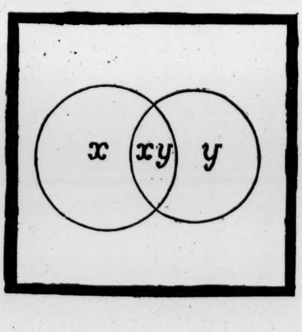
Dr Donaldson concurred with the views of Professor Blackie.

Professor Sellar, while having the greatest admiration for Professor Geddes's knowledge and ingenuity, felt that he had done nothing in the way of enlightening those interested in the subject.

Professor Blackie, in replying, observed that the Society were under obligations to Professor Geddes for having raised the question.

2. The Principles of the Algebra of Logic. Part III.—Application to certain Problems in the Theory of Probability. By Dr Alexander Macfarlane.

The Algebra of Logic, being the science of Necessity and Probability, supplies a variety of methods of great power for solving problems in the theory of Probability. I propose to bring before the Society a few examples extracted from my work on the "Principles of the Algebra of Logic," which is about to be published. A large class of problems, some of which have created considerable diversity of opinion among mathematicians of eminence, can be solved by means of a single theorem. It consists in finding the arithmetical value of $\frac{xy}{x}$. The meaning of this expression is shown by the diagram—



The collection of individuals forming the subject of discourse is represented by the part of the page within the square, those which have a character x by the part inside the one circular line, and those which have the character y by the part inside the other

circular line; those having both x and y by the part inside both lines, those having neither by the part outside.

$$\text{Now} \qquad xy = xy \qquad \therefore\ y = \frac{xy}{x}.$$

Expand $\frac{xy}{x}$ in terms of the parts formed by means of xy and x.

$$\frac{xy}{x} = a\,xy\,x + b\,xy\,(1-x) + c(1-xy)\,x + d(1-xy)(1-x).$$

Let $xy = 1$ and $x = 1$. Then, $a = \frac{1}{1} = 1$.

$xy = 1$ and $x = 0$, then $b = \frac{1}{0}$.

$xy = 0$ and $x = 1$, then $c = \frac{0}{1} = 0$.

$xy = 0$ and $x = 0$, then $d = \frac{0}{0}$.

$$\therefore\ \frac{xy}{x} = xy\,x + 0(1-xy)x + \frac{0}{0}(1-xy)(1-x),$$

and also $xy(1-x) = 0$, as evidently ought to be the case.

By putting in

$$x^2 = x\,, \text{ or } x(1-x) = 0\,,$$

we get $$\frac{xy}{x} = xy + 0\,x(1-y) + \frac{0}{0}(\overline{1-x}),$$

that is, what is y is identical with what is x and y, together with no part of what is x and not y, together with an indefinite part of what is not x. The truth of this is evidenced by the diagram. Since every logical equation is true arithmetically,

$$\bar{y} = \overline{xy} + \frac{0}{0}(1-x);$$

where the bar denotes that the arithmetical value of the symbol is taken.

Applications of the above Theorem.

(1.) The probability that it thunders upon a given day is p, the probability that it both thunders and hails is q, but of the connection of the two phenomena of thunder and hail, nothing further is supposed to be known. Required the probability that it hails on the proposed day.

Let U = a succession of states of the atmosphere at a given place, an individual state being of the length of a day.

x = containing a thunderstorm,
y = containing a hailstorm.

Then the data are—

$$x = \bar{p}, \qquad xy = \bar{q}.$$

Hence, by means of the theorem proved

$$\bar{y} = \bar{q} + \frac{0}{0}(\bar{1} - \bar{p}),$$

$$\therefore \quad \bar{y} > \bar{q},$$

$$\text{and} < \bar{q} + \bar{1} - p.$$

(2.) A says that B says that a certain event took place; required the probability that the event did take place, p_1 and p_2 being A's and B's respective probabilities of speaking the truth.

The solution of this problem recently gave rise to a great amount of discussion in the "Educational Times." No fewer than four different solutions are given, viz.:—

Todhunter—

$$p_1p_2 + (1 - p_1)(1 - p_2).$$

Artemas Martin—

$$p_1\{p_1p_2 + (1 - p_1)(1 - p_2)\}.$$

Woolhouse and American mathematicians—

$$p_1p_2.$$

Cayley—

$$p_1p_2 + \beta(1 - p_1)(1 - p_2) + \kappa(1 - \beta)(1 - p_1),$$

where β is the chance, on the supposition of the incorrectness of A's statement, that B told A that the event did *not* happen, and $1 - \beta$ that he did not tell him at all. κ is the antecedent probability.

Let U = statements of A about B's statements about an event taking place.

x = which truly reported a statement by B,
y = which truly reported the event.

Then

$$x = \bar{p}_1, \quad \text{and } xy = \bar{p}_1\bar{p}_2,$$

therefore, by means of the theorem proved

$$y = \bar{p}_1\bar{p}_2 + \frac{0}{0}(\bar{1} - \bar{p}_1),$$
$$> \bar{p}_1\bar{p}_2,$$
$$< \bar{p}_1\bar{p}_2 + \bar{1} - \bar{p}_1.$$

Todhunter assumes that $\frac{0}{0} = 1 - p_2$; and Woolhouse that $\frac{0}{0} = 0$.

The above solution contradicts the first three, and agrees with the fourth, without introducing more than one unknown quantity. But, by means of the theorem referred to, we can find the solution when there are n persons involved in the tradition.

(3.) A_1 says that A_2 says that A_3 says . . . that A_n says a certain event took place. The probabilities of A_1, A_2, . . . A_n speaking the truth are p_1, p_2, . . . p_n respectively. Required the probability that the event took place.

Let—

U = series of statements of A_1 about A_2 saying &c.,
x_1 = which truly reported a statement of A_2,
x_2 = " " A_3,
. . . . . .
x_n = " " the event.

Now,

$$x_n = \frac{x_1x_2\ldots x_n}{x_1x_2\ldots x_{n-1}}$$

$$= x_1x_2\ldots x_n + \frac{0}{0}(1 - x_1x_2\ldots x_{n-1}) \text{ by the theorem,}$$

$$= \overline{p_1p_2}\ldots\overline{p_n} + \frac{0}{0}(\bar{1} - \overline{p_1p_2\ldots p_{n-1}}) \text{ by the data.}$$

Cor. 1. Suppose that each always reports truly. Then

$$x_n = 1 + \frac{0}{0} \times 0 = 1.$$

Cor. 2. Suppose that each always reports truly excepting A_n. Then

$$x_n = \overline{p_n}.$$

Cor. 3. Suppose that A_n always speaks falsely, then

$$x_n = \frac{0}{0}(\bar{1} - \overline{p_1 p_2 \cdots p_{n-1}}).$$

Cor. 4. Suppose that any other than A_n always speaks falsely, then

$$x_n = \frac{0}{0};$$

that is, the probability is quite indefinite.

Cor. 5. Suppose that each $\bar{p} = \frac{1}{2}$,

then,

$$x_n = \left(\frac{1}{2}\right)^n + \frac{0}{0}\left(1 - \left(\frac{1}{2}\right)^{n-1}\right);$$

which, when n is infinite is equal to $\frac{0}{0}$, that is, is perfectly indefinite.

(4.) A goes to hall p times in q consecutive days and sees B there r times. What is the most probable number of times that B was in the hall in the q days?—*Whitworth's Choice and Chance.*

$$\begin{aligned} U &= \text{the consecutive days;} \\ x &= \text{on which A goes to hall;} \\ y &= \text{on which B goes to hall.} \end{aligned}$$

The data are—

$$U = \bar{q};$$

$$Ux = \bar{p}; \qquad Uxy = \bar{r};$$

∴ by means of the theorem,

$$Uy = \bar{r} + \frac{0}{0}(\bar{q} - \bar{p}).$$

To find the most probable value, make the assumption of independence, that is, that B is as likely to go to hall when A does not go, as when A does go.

Then the most probable value of Uy is

$$r + \frac{r}{p}(q - p) = \frac{rq}{p}.$$

Whitworth gives $\frac{(q+1)r}{p}$, or next lower integer.

Cor. Let $r = p = q$. Then $Uy = q$.

Problems discussed by Boole in the "Laws of Thought."

1. The probability that one or both of two events happen is $\bar{p}$, that one or both of them fail is $\bar{q}$. What is the probability that only one of these happens?

$$xy + x(1-y) + (1-x)y = \bar{p},$$
$$x(1-y) + (1-x)y + (1-x)(1-y) = \bar{q},$$

it is required to find

$$x(1-y) + y(1-x).$$

Let

$$x(1-y)+y(1-x) = a + b\{xy + x(1-y) + (1-x)y\}$$
$$+ c\{x(1-y) + (1-x)y + (1-x)(1-y)\}.$$

$$\begin{array}{lllll} \text{Let } x = 1 & y = 1 & \text{then} & 0 = a + b & \\ \text{,,} \quad x = 1 & y = 0 & \text{,,} & 1 = a + b + c & \\ \text{,,} \quad x = 0 & y = 1 & \text{,,} & 1 = a + b + c & \\ \text{,,} \quad x = 0 & y = 0 & \text{,,} & 0 = a \qquad + c. & \end{array}$$

We have four equations, but two of them are identical. When solved—

$$a = -1, \qquad b = 1, \qquad c = 1,$$
$$\therefore \quad x(1-y) + y(1-x) = -\bar{1} + \bar{p} + \bar{q}.$$

This method by indeterminate coefficients serves to indicate whether a problem is determinate. For example, investigate the first problem by its means—

$$y = a + bx + cxy.$$

Then

$$1 = a + b + c,$$
$$0 = a + b,$$
$$\left.\begin{array}{l} 1 = a \\ 0 = a \end{array}\right\};$$

$$\therefore \quad a = \frac{0}{0}, \qquad b = -\frac{0}{0}, \qquad c = 1.$$

$$\therefore \quad y = \frac{0}{0} - \frac{0}{0}x + xy$$
$$= xy + \frac{0}{0}(1-x).$$

2. The probabilities of two causes A_1 and A_2 are $\bar{a}$ and $\bar{b}$ respec-

tively. The probability that if the cause A_1 present itself, an event E will accompany it (whether as a consequence of the cause A_1 or not) is p_1, and the probability that if the cause A_2 present itself, that event E will accompany it, whether as a consequence of it or not, is q. Moreover, the event E cannot appear in the absence of both the causes, A_1 and A_2. Required the probability of the event E.

The data are—

$$\overline{x} = \overline{a}, \qquad \overline{y} = \overline{b}, \qquad \overline{xz} = \overline{a}\,\overline{p}, \qquad \overline{yz} = \overline{b}\,\overline{q},$$

and

$$(1 - x)(1 - y)z = 0,$$

and $\overline{z}$ is required.

$$\text{Now } (1 - x)(1 - y)z = z - xz - yz + xyz,$$

$$\therefore \qquad z = xz + yz - xyz$$

by the last datum;

$$\therefore \quad \overline{z} < \overline{xz} + \overline{yz} - \overline{x} - \overline{yz} + \overline{1} \quad . \quad . \quad (1.)$$

$$< \overline{xz} + \overline{yz} - \overline{y} - \overline{xz} + \overline{1} \quad . \quad . \quad (2.)$$

$$< \overline{xz} + \overline{yz} \quad . \quad . \quad . \quad . \quad . \quad (3.)$$

$$\therefore \quad \overline{z} < \overline{1} - \overline{a} + \overline{a}\,\overline{p}. \quad . \quad . \quad . \quad . \quad (1.)$$

$$< \overline{1} - \overline{b} + \overline{b}\,\overline{q}. \quad . \quad . \quad . \quad . \quad (2.)$$

$$< \overline{a}\,\overline{p} + \overline{b}\,\overline{q}. \quad . \quad . \quad . \quad . \quad (3.)$$

Also

$$(1 - x)yz = yz - xyz,$$

$$= yz + z - xz - yz$$

by the last datum;

$$\therefore \quad z = xz + (1 - x)yz;$$

$$\therefore \quad \overline{z} > \overline{a}\,\overline{p}.$$

Also

$$\overline{z} > \overline{b}\,\overline{q}.$$

This problem was discussed in the "Philosophical Magazine," by Boole, Wilbraham, and Cayley. Cayley's solution is different, applying to a modification of the problem. Boole goes further, and finds the most probable value of the probability. Wilbraham considers only mathematical probability, and maintains, quite rightly, that we cannot proceed further than above without making assumptions. He says that the disadvantage of Boole's method is, that it does not show whether a problem is determinate. This desideratum is supplied by the method of indeterminate coefficients to which I have referred above.

Monday, 21st April 1879.

PROFESSOR MACLAGAN, Vice-President, in the Chair.

The following Communications were read:—

1. The Anatomy of the Northern Beluga (*B. Catodon*) compared with that of other Whales. By Morrison Watson, M.D., F.R.S.E., and Alfred H. Young, M.B., &c., Owens College, Manchester.

(*Abstract.*)

The specimen which formed the subject of this memoir was one of three, imported into England by Mr Farini of London.

The skeleton being already well known, and the state of the parts preventing an examination of the muscular anatomy, attention was directed solely to that of the viscera, of which no complete description had hitherto been given. Drs Barclay and Neill in this country, and subsequently Professor Wyman in America, had previously investigated some points in the anatomy of the soft parts of Beluga, but their descriptions are so fragmentary as to necessitate a more accurate and extended investigation of the viscera.

In addition to a full description of the various organs, a comparison is instituted between these and the corresponding structures of other Cetaceans.

With regard to the relation in which Beluga stands to other genera, the comparative observations detailed in the memoir show that, so far as the soft parts are concerned, Beluga in many respects presents a close resemblance to Grampus and to Globio-cephalus, whilst it differs from both in several minor points. From an examination of the skeleton, Professor Flower[1] concludes that "the Narwhal and the Beluga appear to separate themselves from all the rest, by certain well-marked structural conditions, especially in the characters of the cervical vertebræ. As these two animals are in almost every part of their skeleton nearly identical," Professor Flower is disposed "to unite the two genera into a distinct sub-family, placing it next to the Platanistidæ." Unfortunately, such information as we possess regarding the soft parts of the Narwhal is of too imperfect a character to admit of the comparison being fol-

[1] Trans. Zool. Soc. vol. vi. p. 115.

lowed out. If, however, the number and arrangement of the nasal sacs, as forming an element in the determination of the affinities of different Cetaceans, is deserving of the importance attributed to them by some writers, those of Beluga certainly seem to associate that genus with Monodon, and to separate it from the other genera above named. It should, however, be noted that the sub-division of the trachea into *four* bronchi in Monodon is widely different from that which obtains in Beluga and in every other toothed whale of which we have any knowledge, with the single exception of Pontoporia. In view of the scantiness of information regarding the anatomy of Monodon, the determination of the exact affinities of Beluga must be left to future observers.

2. Fifth Report of the Boulder Committee.

The Committee had submitted to them Notes by the Convener of two visits to the West Highlands (including the Outer Hebrides) which he had made during the summer and autumn of 1878. These Notes, accompanied by diagrams of boulders and striated rocks, afford a large amount of information bearing on the subject of boulder transport, the direction of transport, and the agent of transport.

There has also been laid before the Committee a report by William Jolly, of Inverness, one of its members, "On the Transportation of Rocks found on the Shores of the Moray Firth;" as also Notes by Messrs Somervail and Henderson (Edinburgh), "On Boulders and Striated Rocks in the Pentland Hills."

The Committee have had an opportunity of seeing these Notes and Reports in printed proof sheets. The Convener, on his own responsibility, sent the MSS. to the printer; and the Committee approve of his having taken this course.

Notes by Convener of two Visits to the West Highlands and Hebrides in Summer and Autumn of 1878.

I.—Island of Iona.

The Convener having occasion to be in this island for a few hours, went to the boulder referred to in the Committee's Second Report, situated on the west side of Dun-Ii hill.

Its peculiar position appearing to him to deserve a more special notice, he gives in fig. 1 a sketch of it taken from the north.

The boulder consists of a coarse-grained granite. But in Iona there is no granite rock of any kind. The prevailing rock is a fine-grained gneiss, approaching in many places to clay slate.

Captain Stewart of Coll was with the Convener when he examined the boulder. On breaking off portions from it, and also from another small boulder lying below, exactly similar in composition, he at once said, "This is Coll granite."

These Iona boulders, in respect both of situation and position, undoubtedly indicate, that they were lodged by some agent which brought them from the N. or N.W. That agent had stranded upon the hill and stuck there till the boulders dropped from it.

From no eastern quarter could the boulders have reached their position. Their site is 250 feet above the sea. The hill on which they are, being 350 feet high, and forming a ridge of about a quarter of a mile running north and south, would preclude access from any eastern point.

The granite in the Ross of Mull, situated to the east of Iona, is different in composition from that of the boulders now referred to. On the east side of Iona there are granite boulders, similar to the Mull granite, as mentioned in the Committee's second Report. But the boulders on the N.W. shoulder of "Dun-Ii" are larger grained and of a different colour; and they occupy a level considerably above most of the granite rocks at the Ross of Mull.

With reference to Captain Stewart's remark, as to the large boulder above referred to being of the same kind of granite as in the island of Coll, the suggestion is so far favoured by the position of Coll, which bears about N.N.W. from Iona, and is distant about 20 miles. But on the other hand, the Convener must state that when he visited the island of Coll a few days afterwards, he found that the *rocks* everywhere were gneiss, and with only occasional veins of granite. The boulders he saw on Coll were of granite.

II.—ISLAND OF TIREE.

1. Heynish Hill, situated near the S.W. end of the island, reaches a height of about 600 feet above the sea-level. This hill consists chiefly of gneiss rock, though in some parts the ingredients become so coarse as to pass into granite.

The hill was ascended from the south side, under the guidance of Mr M'Quarrie, who is tenant of an extensive farm, on which the hill, or the greater part of it, is situated.

The hill on its west side abuts on the sea cliffs. The slope of the hill there has on it a number of rocky knolls.

Almost every knoll has on its N.W. side, facing the sea, boulders, more or less rounded.

The following are the dimensions of some of the larger boulders:—

(1.) 11 × 8 × 5 = 440 cubic feet, resting on the side of a knoll facing W.N.W.

(2.) 9 × 4 × 5 = 180 cubic feet, resting on the side of a knoll facing W. by N., at height of 360 feet above the sea, which is a quarter of a mile distant, and open between S. and N.N.W. This boulder is a coarse granite;—the knoll is gneiss.

(3.) 8 × 7 × 5 = 280 cubic feet, resting on the side of a knoll facing N.W. by N., at height of 365 feet above the sea. Sea is quarter of a mile distant, and access from it is open at any point between S.W. and due north.

(4.) Two clusters of large boulders were met with, the uppermost so placed as to show that it must have come from the westward. The sea is within half a mile to the westward.

On this Heynish hill, the boulders are more numerous on the sides facing the W. and N.W. than on any other side. On the slopes facing the E. and S.E. there are also boulders, but in numbers not nearly so great.

2. After examining Heynish hill, the Convener passed through the island about due north along what is called the Big Cornaig Road. To the eastward of this road there are several rocky knolls, the tops of which are from 80 to 110 feet above the sea. Most of them present bare rock on their west sides, and have boulders also on these sides. One of these knolls was ascended, called "Drumbuim" (meaning yellow rock), for the examination of a boulder observed to be very near its top. Its dimensions were 10 × 6 × 6 = 360 cubic feet. It consisted of a light coloured gneiss;—the rock of the knoll is also gneiss, but dark coloured.

Another rocky knoll, about a mile to the N.E. of the last, was visited to see some boulders, nicknamed, in Gaelic, "The Giant's Pebbles." The legend, as related by a native resident near the

place to the Rev. Mr M'Donald of Helipol, who was the Convener's guide on this occasion, is that three giants living in Barra, wishing to try how far they could throw a stone, took the largest pebbles they could find at Barra, and flung them in the direction of Tiree, which is situated S.E. of Barra, and about 40 miles distant. The story goes, that the stones reached Tiree, and fell very near one another. The knoll referred to is clustered over with huge boulders. Three or four are from 8 to 10 feet high, and from 20 to 25 feet along each side. There may be about 20 or 30 boulders of all sizes; they are on the knoll, and none on the flat ground adjoining, a circumstance suggesting that the knoll, by being above the adjoining surface of the land, had intercepted the agent which was carrying the boulders, and caused them to be deposited there.

3. "*Ben Gott*" hill, on the north side of Tiree, forms a ridge running north and south for about a quarter of a mile, and is from 120 to 130 feet above the sea. A very large number of boulders, chiefly gneiss, are on its N.W. flanks. A few occur on the flat summit, and some are also on the S.E. slope, as if they had been pushed over the top from the N.W. On the flat ground beyond the limits of the hill towards the S.E. there are few or no boulders.

4. In Tiree, the evidence of the sea having stood recently at a higher level is very striking. On a great part of the island there are extensive beds of a stratified muddy sand, sometimes 15 to 20 feet deep, evidently a sea deposit. In other parts of the island there are huge beds or banks of shingle, composed chiefly of well-rounded pebbles of hard gneiss rock, similar to what occurs on the existing shores of all the Hebrides, at places exposed to the action of heavy sea waves. The pebbles in these shingle banks sometimes are twice the size of a man's head, but the great mass of the pebbles are half of this size. They point to a period when the sea must have stood here at least 40 feet, probably more, above the present level, and when, by the force of the waves, fragments of gneiss rock were worn down into elliptic, and sometimes even perfectly spherical, forms. The Convener brought away a few specimens.

III.—ISLAND OF COLL.

1. Under the guidance of the Rev. Mr Fraser, Free Church minister, the Convener visited Bein Hock, a hill on the west side of

the island and very close upon the sea. Its highest point is about 290 feet above the sea.

At the foot of this hill there is another low hill, called Bein Meanach, above 80 feet above the sea. Fig. 2 gives a sketch of both hills. Ben Hock has two boulders on its top, the smaller one, A, 260 feet, the larger one, B, 270 feet above the sea. Enlarged views of these are given in figs. 3 and 4, to show their size and position, and the fact (which Mr Fraser thought curious) that each rests on three smaller boulders. A rests on a rock surface sloping down N.W. at an angle of 16°. The rock on which B rests is nearly flat.

The boulder C on Meanach has nothing peculiar about it, except for size—it being 16 × 20 × 13 feet.

These boulders are a coarse granite, which, however, in some parts passes into a dark-coloured gneiss. The rock of the hill is also gneiss; but they are all veritable erratics, and must have come from some region in the N.W.

2. Mr Fraser next guided the Convener to a spot situated about half-a-mile to the east of Ben Hock, at Grassipol, that he might look at what he (Mr Fraser) considered to be an immense accumulation of boulders.

The Convener, on viewing the place from a distance, thought that the blocks might be only fragments from a cliff adjoining, and not erratics; but, on going to the spot, he found they were boulders, and in positions of much interest. They were lying in many cases over one another on a flat meadow, and formed an elongated heap, more or less parallel with the line of a hill distant thirty or forty yards from them to the S.E. The meadow extended N.E. and S.W. about 350 to 400 yards, and towards the N.W. about 200 yards—viz., in width. The height of the meadow above the sea was about 80 feet. The sea was situated to the N.W., and distant about three-quarters of a mile. The height of the hill above the meadow on the S.E. was about 80 feet. A few boulders were lying scattered on the slope of this hill facing the N.W. It was manifest that the great accumulation of boulders on the meadow along the base of the hill could be best explained by supposing that the boulders had all come from the N.W., and had been stopped by the hill in an easterly movement. One of the boulders

on the meadow was 30 feet in height. (Fig. 5 gives a view of this spot.)

Near the west end of the hill just referred to there was a projecting knoll which had apparently intercepted a number of boulders. There were about twenty altogether piled on one another, and so piled as to indicate that the uppermost could not well have obtained its position except by coming from a N.W. direction. (Fig. 6 is intended to show this cluster of boulders.)

Close to this place there was a vein of quartz, which showed a smooth surface, sloping down towards the N.W., as if polished by some agent which had pressed heavily over it from that direction.

3. In crossing the island, from Arinagour on the east coast to Bein Hock on the west, by the road leading past Arnibost schoolhouse, there is a manifest difference in the size and number of the boulders. At and near Arinagour the boulders are few in number, and small. At and near Arnibost, which is about a mile inland, they become numerous, and occupy significant positions, many being on smoothed rocks facing the west.

At Grassipol, and on the sea-coast adjoining Bein Hock hill, there are boulders of enormous size. The rock on which most of these boulders lie is about 90 feet above the sea, and slopes down towards the W.N.W. at an angle of about 10°. It presents a surface due apparently to some powerful agency which has levelled and smoothed it. Many other examples of this can be seen, close to the highroad near the schoolhouse of Arnibost, and particularly on the low rocky hills south of the road.

These smoothed rock surfaces, sloping down towards the northwest, are easily distinguishable from the natural surfaces of the rock strata. The gneiss rock, especially in this part of the island, is seldom in the form of regular beds. Where such occur, the dip is not towards the N.W., but towards the S. and S.E.

At the S.W. end of the island there are several granite boulders lying on gneiss rocks. One, which was the largest he saw, attracted the Convener's special attention, lying close to the mansion-house of Coll, belonging to Mr Stewart. Its length was 35 feet, its width 15 feet, and its height above the surface of the ground 8 feet. It was leaning on, or at all events pressing against, a mass of gneiss rock on its S.E. side. The granite was coarse-grained

and reddish, because of the felspar in it. Preparations were being made for blasting the boulder. As Captain Stewart was well acquainted with this huge block, he had been probably thinking of it when he saw the Iona Boulder, and compared it to Coll granite.

4. Macculloch, in his account of the geology of Coll, refers to a "block of *augit*" which, he says, he found at a great distance from the shore, and which he thought must "be a *transported* block," as he had seen no such rock *in situ* in the island, and he throws out a conjecture that it may somehow have come from Rum, of which island augit, he says, forms a large portion. This block of augit the Convener did not meet with.

The island of Rum is situated north by east of Coll, and distant about twenty miles.

5. It is somewhat curious that two of these Coll boulders should be described in Dr Johnston's narrative of his tour through the Western Highlands, and in Boswell's Diary. The passages are as follows:—

Johnston says:—"For natural curiosities, I was only shown two great masses of stone, which lie loose upon the ground—one on the top of the hill, and the other at a small distance from the bottom. They certainly were never put into their present position by human strength or skill; and, though an earthquake might have broken off the lower stone and rolled it into the valley, no account can be given of the other which lies on the hill, unless (which I forgot to examine) there be still near it some higher rock from which it might have been torn. All nations have traditions that their ancestors were giants, and these stones are said to have been thrown up and down by a giant and his mistress."

Boswell, in his notes referring to these boulders, says:—"Coll and I passed by a place where there is a very large stone—a vast weight for Ajax. The tradition is, that a giant threw such another stone at his mistress up to the top of the hill at a small distance, and that she, in return, threw this mass down to him—all in sport. *Malo me petit lasciva puella.*"

Again Boswell writes, 9th October 1784:—"As in our present confinement, anything which has even the name of curious was an object of attention, I proposed that Coll should show me the great

stone, mentioned in a former page as having been thrown by a giant to the top of a mountain. Dr Johnston said he would accompany us as far as riding on horseback was practicable—which he did. Coll and I scrambled up the rest. Dr J. placed himself on the ground, with his back against a fragment of rock, while we were employed examining the stone, *which did not repay our trouble in getting to it.* Dr J. amused himself reading a book which he found in the garret of Coll's house."

The stone mentioned in these extracts as at the "top of a mountain," is the one at the top of Ben Hock, marked B, and shown in fig. 4.

The other stone, mentioned as being at a "small distance from the bottom," is C.

Boswell observes that an examination of the boulder at the top of the hill did not repay his trouble in getting to it; but, if he had been able to elicit, from a study of the boulder and its site, the information which geological science now reveals, he would have thought that the trouble of getting to it was well repaid, and he would have been able to give a more probable explanation of how it came to the top of the hill, than that a giant threw it up there at his mistress.

IV.—ISLAND OF STAFFA.

In the Committee's second Report notice is taken of a hasty visit to this trap island by the Convener, which, having occurred on a stormy day, afforded an opportunity of discovering only one or two blocks of red granite.

On account of the interest of finding on an island boulders or even pebbles of rocks, not existing there *in situ*, the Convener, in June last, paid another half-hour's visit to Staffa, by means of the passenger steamboat, which takes tourists to the caves.

He remembered that, on the occasion when he formerly visited the island, the boulders fallen in with were chiefly in the foundations and walls of ruined cottages and sheep stalls. The basaltic rocks of the island were no doubt found less suitable for building purposes. On this occasion, by the advice of the captain of the steamer, the Convener sought for pebbles and boulders in a small bay on the east side of the island. He found several small boulders

lying on the surface, not only of red granite, but also of gneiss, quartzite, and limestone, none of which occur as *rocks* or *strata* in Staffa.

About fifty yards from this place, a bank of consolidated shingle was observed, apparently an old sea beach about 36 feet above high water-mark, from the breaking up of which, in all probability, the boulders above specified were derived.

Dr Macculloch, when he visited Staffa in 1818, noticed these boulders, and was much puzzled to account for them. He says—"I must not quit Staffa without describing a bed of matter which, however foreign to the structure of the island, is by no means foreign to its mineral history, giving rise, at the same time, to geological questions of considerable importance. This is an alluvial deposit, consisting of various *transported stones*, which may be seen on the surface in different parts of the island. It is particularly conspicuous near the landing place, and on the western abrupt edge of the cliff. The fragments are of various kinds—quartz, granite, and blue schist, intermixed with blue quartz rock, and trap—all of them substances which enter into the composition of the neighbouring islands of Rum, Skye, and Mull, but which are found *in situ* no nearer than in the latter island. The distance of Staffa from Mull is not less than seven miles. The surface of the Earth everywhere presents appearances indicating great changes and revolutions, of which none are more unquestionable than the existence of transported stones and alluvial substances in countries far removed from those where similar rocks are now found in their natural situations. The insular position of the example now under consideration, proves that it could not have resulted from the flow of water, whether that flow was gradual or sudden, without at the same time supposing a state of the surface in which Staffa was continuous, at least, with the neighbouring island of Mull." (Vol. ii. p. 22.)

Macculloch here evidently alludes to the theory originally propounded by Sir James Hall for explaining the transport of boulders by a diluvial current. To render such a theory applicable to the Staffa boulders, Macculloch assumes the necessity of joining the island to Mull, though there are now seven miles of sea between them, with a depth of 50 to 60 fathoms. At that time, the idea

of ice, in any form, as a medium of transport had not been thought of.

V.—ISLAND OF BARRA.

This island, near its north end, contains a magnificent boulder. Its size exceeds that of any seen by the Convener in Scotland, and the site it occupies is full of interest. The legend, before referred to, of giants in Barra throwing large boulders to Tiree, may have been suggested to the Tiree people, by hearing that very large boulders existed in Barra.

On figs. 7 and 8, two views of this boulder are given, both from the north. The first view is taken at about 200 yards, the second about 50 yards distance.

The boulder rests on a broad mass of gravel and sand, with numerous cockles in it, at a height above the sea of 230 feet. It is distant from the sea about a quarter of a mile. The present shore is to the north. The great open ocean is chiefly to the N.W., and very partially to the N.E.

The Convener dug below the boulder in several places, and found everywhere sand and fine gravel. A number of rabbit burrows, under and about the boulder, confirmed this observation regarding the materials of the site.

The height of the boulder is about 25 or 26 feet. Its extreme length is from 37 to 38 feet; and its width about 18 feet—assuming two tons for a cubic yard, the weight of the boulder would be nearly 890 tons.

The longer axis of the boulder was found to be N.W. by N.

The flat on which the boulder rests, consists apparently of a sea deposit.* Patches of a similar deposit occur in several spots round and near the boulder, and at higher levels. For example, there is a rocky knoll, about 100 yards to the west, clustered with boulders, 255 feet above the sea. These boulders are lying partly on rock, partly on the shelly gravel. Ben Erival is a hill adjoining the big boulder on the south, and reaching to a height of about 600 feet above the sea. Sand with shells was found among the rocky crevices of the hill, up to a height of 457 feet.

The boulder consists of a coarse gniess almost approaching granite.

* See note on page 67.

The gniess of Ben Erival, and of the other adjoining rocky knolls, is more close-grained in composition.

On fig. 9 there is a ground plan, from memory, showing the position of the boulder in relation to adjoining hills. Ben More, which reaches a height of 330 feet above the sea, and is about a mile to the north, is covered with thick beds of sand and fine gravel, full of cockle and other sea shells.

It is also worthy of notice that at present, the bay, immediately to the north of Ben Erival, has in it an immense bed of living cockles—so immense that it is found profitable to gather them from time to time, and send them to Glasgow for sale.

There is something therefore in the sea or the sea-bottom in this district, which now as formerly favours the growth of the *Cardium edule.*

That this "Big Rock of the Glen" forms a veritable boulder, and that, when it was brought to the spot which it now occupies, it was deposited on what was then a submarine bank, not much doubt can be entertained.* The boulder must therefore have been floated to the spot where it now lies—but from what quarter? From the S., S.E., or S.W., come it could not;—as Ben Erival, on whose north flank it rests, and which ranges for about two miles east and west, precludes that idea. There being open sea to the N.W. and N.E., from either of these quarters it might have come, but from no other.

The plan on fig. 9 explains more clearly how the boulder might have been floated from these quarters, and been intercepted in its further progress to the south by Ben Erival.

An examination of the numerous smaller boulders in this district, also indicated transportation from some point between west and north. The following are cases:—

1. To the west of the big boulder, and about 100 yards distant, there is a small but steep rocky knoll (fig. 9, letter *b*) whose top reaches to a height of 255 feet above the sea, and which is covered with boulders, especially on the N.W.

On a minute study of the relative positions of the boulders on this

* The submarine character of the bank does not depend solely on the presence in it of sea-shells, for they might have been blown up from the existing sea-shore by storms. But the materials forming the bank being found, by digging under the boulder, to consist of sand and gravel, they afford the strongest evidence of a submarine origin.

knoll, it was found that those which were uppermost must have come from the N.W., otherwise they could not have got into the positions they occupy.

There were no boulders near the top of the knoll on the S.E. side; but at the base of the knoll on that side, several boulders were lying, which might have fallen from the top. They were not heaped on one another, as they were at the top of the knoll, but lying separate.

2. About 200 yards to the N.E. of the big boulder there is a boulder on smoothed rock which dips due north at an angle of 20°. The size of the boulder is $5 \times 4 \times 4$ feet. The steepness of the rock surface on which it lies, is so great, that it would have a better chance of obtaining and retaining its position by coming from the north, than from any other quarter.

3. About 300 yards to the S.E. of the "big boulder" there is a boulder $8\frac{1}{2} \times 6 \times 5$ feet, at a height of about 228 feet above the sea, shown on fig. 10. The boulder at its east end presses closely on a rock, which has prevented it moving further in an easterly direction.

4. On the N.W. side of Ben Erival, where its sides slope down steeply to the sea, there are numerous boulders, and many of them pressing in like manner against the rocks of the hill, in such a way as to show that they must have come from some point between west and north. They are at various heights, from 400 to 500 feet above the sea.

5. There is a low hill to the N.N.W. of Ben Erival, adjoining "*Traigh Vore*," or Great Strand (a narrow neck of sand which here separates the east and west shores), through part of which an open fissure in the solid rocks runs for some distance. It has evidently been one of those rents alluded to by Macculloch in his Account of Barra, which had once been filled by trap, but "of which the exposed portions have been washed out." (Vol. i. p. 89.)

The height above the sea-level is about 120 feet.

For about 80 yards, this rent or fissure now presents two vertical walls of gneiss, from 11 to 12 yards apart, and from 8 to 14 feet high.

The direction of the rent is (by compass) N.W. and S.E. The rocks on the *north* wall are rounded, and in many places present

smoothed surfaces. The rocks on the *south* wall are rough and jagged. The appearances on the north walls can be naturally accounted for by the action of a strong sea current moving from W.N.W., which would, with any bodies floating in or swept along by it, grate against the north, but not against the south wall. (See fig. 11.)

6. Ben More is a hill on the farm of Eoligarry tenanted by Dr MacGillivray. Its west end forms a steepish sea cliff, rising up to a height of 330 feet above the sea. Half way up this sea cliff, there is a boulder, 20 × 10 × 5 feet, resting on the rocky surface, which here dips towards the W.S.W. But the rock, judging by the marks on it, has been smoothed by something passing over it from the N.W., and the boulder is blocked at its S.E. end by a vertical portion of the hill, as shown on fig. 12.

7. At Castle Bay, which is at the south end of Barra, the hills are seen to be more covered with boulders on their N.W. sides than on any other. This observation, however, was made only from the steamboat.

Mr J. F. Campbell, in his paper on the "Glacial Phenomena of the Hebrides," states that, in Sept. 1871, he took rubbings of striæ at Castle Bay, showing that the striating agent had come from N. by W. (magn.)

He mentions also that on the small island of Bernera, above 12 miles to the south of Barra, "the last of the Hebrides," he got striæ at a height of 720 feet above the sea, crossing the strike of the rock, from N.N.W. (*Lond. Geol. Soc. Journal*, vol. xxix.)

In coasting along the east shore of Barra it is perceivable, from the deck of the steamboat, that the rocks on the sea cliffs which face the N.W. have been smoothed, whilst the rocks facing the east are rough and jagged.

8. On the hill called Scurrival, whose west side rises abruptly up from the sea to a height of about 240 feet, the hard gneiss rocks present many proofs of grinding, and also of transporting agency from the N.W.

The rock-strata here are tolerably horizontal and form blocks lying about north and south. The vertical sides facing the sea present frequent smoothings, which could have been made by the action of a strong N.W. current, especially if loaded with

ice. (See fig. 13.) The surfaces facing the east present no smoothings.

The examples are numerous on this hill of boulders blocked on their S.E. ends or sides. They are cases exactly similar to that shown on fig. 12. These boulders are within 200 yards of the open ocean, and less than 100 feet above its level. The situation and position of these boulders combine to show that they *must* have come from the westward—though in that direction there is only the wide Atlantic.

At the very top of the hill, which consists of well rounded and smoothed surfaces of gneiss, numerous boulders lie scattered—most of them on that part of the top facing W.N.W.

VI.—ISLAND OF SOUTH UIST.

1. Beginning near the south end, notice has to be taken of a well striated gneiss rock, recently exposed by the removal of materials for the high road. The spot is on the east bank of Loch Dunkellie and at the west side of a hill called Carshavaule, which is marked on the Admiralty map as 226 feet high. The striated rock is only about 20 feet above the sea-level.

The rock had been covered by a bed of coarse sand intermixed with clay, so that its surface had been protected from the weather. The protecting cover contained numerous pebbles, hard and angular, the pressure of which on the rock, if they passed over it, would probably cause striæ.

The rock consists of strata which dip W.S.W. at an angle of about 10°. They were thus conveniently situated for being struck and pressed on by any striating agent from the west.

The lengths of the blocks rounded and striated were respectively, 4, 7, and 5 feet.

The striæ run in a direction N.W. by N. and slope up towards S.E. by S.

If these striæ were caused by rough stones carried in a strong current flowing from the N.W., or pushed by floating ice, the striæ would slope upward in the above direction, because the current would in this low lying spot have to rise, to pass through a valley situated close at hand, immediately to the south of Carshavaule hill.

Mr J. F. Campbell in his paper (before referred to) states that in

a quarry by the roadside of Boisdale in South Uist, he observed "striæ running from N. 40° W. (magn.) pointing at a gap in the hills." This is probably the same spot as that noticed by the Convener. It was shown to him by Mr Drever, factor to Mrs Gordon of Cluny.

2. Loch Boisdale, a sea loch, is situated on the east coast. On the north side of the loch, there is a hill called Kennet, reaching to a height of about 890 feet.

The rocks on its N.W. side, from bottom to top, present numerous examples of flattened and rounded surfaces. The surfaces facing the S.E. on all sides of the hill are rough and angular. On the west side of the hill, at various levels between the bottom and the top, there are numerous boulders, some of them, by the way in which they lie, affording unmistakable evidence of the direction from which they came.

For example, there are two boulders on a narrow shelf of rock which slopes down S.W. at an angle of 40°. The shelf is 96 feet above the sea, and quite close to the sea. The shelf is on the sea cliff, which is so steep, that the wonder is, how the boulders could have found a cleft in it to hold them. (Fig. No. 14 shows these boulders.) On the east side of the boulders there is a projecting ledge, against which the eastmost boulder (A) presses, and which had stopped its farther progress eastward. Another boulder (B) lies upon (A), and which, to get on the top of (A), must have come from some westerly point,—probably the N.W. A line through the chief points of contact and the centres of bulk runs in a direction N.N.W. A study of the boulders on the spot showed that, if they had been brought to this site from any other direction, they would inevitably have slid down the steep rocky bank into the sea. These blocks are nearly equal in size, viz., about $5 \times 3 \times 2$ feet.

Fig. 15 shows a large boulder of coarse granite resting on a wedge of gneiss rock. The wedge or knob is under the boulder at its east end, and tilts up the boulder slightly so as to show daylight under the boulder at that end. It rests on the ground chiefly at its west end. By this wedge (*a* in the figure) the boulder has evidently been stopped in its progress from the N.W. From its rounded shape, one might infer that the boulder had been rolled or

pushed for some distance before it was stopped. The west side is much rounder and smoother than any other side; so, probably after it had stuck, the current which brought it, beat and chafed on its west side, and smoothed it. This boulder lies on a level plateau of rock about 202 feet above the sea. It is all open country towards the N.W. and N.E., whilst the Kennet hill, reaching to a height of 890 feet, is within half-a-mile of the boulder to the S.E. and E.S.E.

On the west slope of this hill, at a height of 300 feet above the sea, the gneiss presents a rocky surface sloping down towards the west at an angle of about 10°. A boulder of coarse granite, 7 × 6 × 4 feet, rests partly on it and on another smaller boulder underneath. This boulder, at its S.E. end, abuts against the rock. It has come, therefore, almost certainly, from some north-westerly point and stuck there. (Fig. 16 represents this case.)

Not far from the top of the hill, viz., at 712 feet above the sea-level, there is a very large angular boulder on a flat ledge of rock, on the N.W. side, with open country in that direction. This boulder is 19 × 13 × 8 feet. Its further progress eastward has evidently been stopped by a projecting cliff of the hill on its south-east side, as shown in fig. 17.

3. Several large boulders may be seen at a small village, where the Free Church and Roman Catholic Church are situated at a junction of the roads from Barra and Loch Boisdale, about two miles to the south of Askernish. There is here a whole cluster of boulders. One, 16 × 6 × 5 feet, leans slanting upon the others, and must have come from the N.W. to attain its position.

4. On the hill to the east of Askernish, and on its side facing the west, there is a surface of rock, sloping down W.S.W. at an angle of 30°, well smoothed. A boulder rests on this slope, partly on the surface of the rock and partly on some smaller boulders which lie between the rock and it, near its S.E. end. The boulder has evidently obtained its position by coming from the N.W.

This is more clearly proved by a number of ruts or striæ, visible on the rock a few feet below the boulder, which run, as shown on fig. 18, by the arrows, in a direction from N.W. to S.E. That the striating agent first struck the rock from the N.W., is made evident by the circumstance that most of the striæ are deeper and wider at

their N.W. than at their S.E. ends. This change in the striæ can be accounted for by supposing that the striating agent as it moved over the rock, acted with a lessening pressure, by having rebounded from the rock after the first impact.

5. On Mingary Hill, reaching a height of about 600 feet above the sea, three miles N.E. of Askernish, many boulders occur, especially, as usual, on the N.W. flanks. Most of them occupy separate spots—but in some places they are in clusters—heaped on one another. In this last class of cases, there is generally a knoll of some kind standing up above the general surface, on or round which the boulders lie.

One of the most interesting spots on this hill is a spur from it projecting N.W., to which Mr Drever (who resides at Askernish), conducted the Convener. His object was to point out there a boulder of considerable size which had shortly before been seen by Mr Jolly of Inverness. The hill in question is shown in fig. 19. The hill here reaches to a height of 270 feet above the sea, and it slopes down at an angle of about 15° to the N.W. But about 30 or 35 feet from the top, there is a horizontal plateau, on which a number of boulders lie together. Has this been an old sea-margin, from which the smaller stones have been washed away, leaving on it, as on a beach, the heavier boulders? The largest boulder in the figure, lower than all the rest, is 11 × 9 × 8 feet. It lies on bare rock sloping down towards the N.W., from which quarter it, as well as all the others, had apparently come. The transporting agent seems to have struck upon the hill, and discharged its cargo there.

Very near the top of the hill, there is a rocky surface, rounded and striated, the striæ running N.W. by N. A vein of quartz about 3 inches wide crosses this rock, and for about 12 inches it presents a beautifully smoothed surface.

6. At a place called Jocdar, situated on the main road one and a half mile south of the Ferry between Uist and Benbecula, smoothed rocks have been exposed to view by the removal of gravel, &c. These rocks are at a height of about 25 feet above the sea. The rocks are literally covered by parallel striæ, ruts, and grooves, the direction of all which is N.W. by W.

On these rocks there are twelve or fourteen deep ruts and

grooves, some of them 4 or 5 feet in length. One of them, at its N.W. end, measures 8 inches across, and 2 inches in depth; another measures at its N.W. end, 12 inches in width, and $1\frac{1}{2}$ inch in depth; another 9 inches in width, and $1\frac{1}{4}$ inch in depth. These, and most of the others, show a greater depth and width at their N.W. than at their S.E. ends. In fact, they all gradually lessen and disappear towards the S.E.

At this place, the smoothed faces of the rock slope at an angle of 10° or 12° to the westward.

7. There is another exposure of well rounded, smoothed, and striated rocks, close to the Ferry between Benbecula and Uist—*i.e.*, about half a mile to the west, on the south side of a bye road. The rocks are here, as at the place last mentioned, of hard gneiss, and most beautifully polished. They had been covered by a bed of clay containing numerous hard pebbles, a portion of the bed still remaining upon the polished rock. Here, as at Jocar, some of the grooves are several inches in width, and as much as 2 inches in depth, and several feet long. The deepest and widest ends are also, as before, at the N.W.

One of the rounded rocky bosses is polished not only on the top but at the sides, as shown on fig. 20. Having regard to the bearings of the knoll, which is elliptic in shape, the polishing and striation on both sides could have been effected only by a current flowing from the N.W.*

8. On the road between Grogarry (the mansion-house of Mrs Gordon of Cluny) and Loch Skiport (on the east coast), the following places of interest were observed:—

At about $1\frac{1}{2}$ mile from Grogarry, on the south side of the road, the hard gneiss rock, which had recently been uncovered, was found to have been ground down and polished into extensive surfaces dipping N.N.W., at an angle of about 20°. These surfaces were covered by innumerable striæ, and by several ruts and grooves—all running in a direction E.S.E. up the face of the rock at an angle of 7° or 8°. It is very probable that a current from the N.W., loaded

* These two beautiful examples of rocks, smoothed and striated, at Jocar and at the Ferry, were pointed out by Alexander Carmichael, Esq., Creagorry, who resides near the Ferry. Both he and Mrs Carmichael took much interest in the Convener's researches, the latter kindly giving to him sketches which she had made of several interesting boulders.

with hard gritty materials coming against the rock dipping as above explained, would be deflected in its course along the face of the rock from S.E. to E.S.E. At the N.W. end one groove measured 2 inches wide and $\frac{1}{4}$ inch deep; another, 2 inches wide and $\frac{1}{8}$th inch deep. They became fainter towards their S.E. ends.

At another place on the road side, the striæ ran W.S.W., but the surface of the striated rock faced the south, and it was in a confined valley only about 30 feet above the sea.

On the hill adjoining, 122 feet above the sea, a granite knoll on an open moor showed a deep rut about 18 inches long, running from W.N.W., its west end being deepest and widest.

At another place the boulder had in its progress eastward been intercepted by a vertical ledge of rock at its east end, and it was resting on a horizontal bed of rock, just as in figs. 10 and 12.

At another place there were 5 or 6 huge boulders piled over one another, all resting on a rocky knoll, standing above the general surface of the adjoining district. The topmost boulder, lying in a slanting position on the others, could have obtained that position only by coming from the westward. This spot was 80 feet above the sea.

About 3 miles to the north of Askernish, on the east side of the main road, there is a perched block of granite, on the pointed summit of a rocky hill about 130 feet above the sea. Two views are given in figs. 21 and 22. The base on which the boulder stands is exceedingly narrow. The boulder is in size $14 \times 12 \times 8$ feet, and its contact with the rock is only 6×4 feet. A steep hill rises near the boulder on its east side, but the boulder could not have fallen from it. That hill would arrest an iceberg or ice-floe, if the boulder came in that way from the west. As the ice melted, the boulder might have subsided gently on the peak. Some smaller boulders cap a rocky knoll below, as shown on the figures. All these indicate transport from the N.W. by some means.

9. *Loch Eport* is a remarkably narrow arm of the sea, on the east coast, which runs more than half-way across North Uist, towards the west coast. From the deck of the steamboat numerous boulders were seen, most of them resting on knolls. The smooth faces of the rocks were all strikingly towards the N.W., whilst the rough and jagged rocks all fronted the S.E.

(10.) *Loch Maddy*, a sea loch on the east side of North Uist. A walk for about a mile among the hills, during an hour that the steamboat was discharging cargo, showed that the rocks had their smoothest sides towards the N.W., and their rough sides towards the S.E. Boulders in great numbers were lying on these smoothed surfaces, and on the N.W. sides of the hills.

Before concluding his notice of Uist, the Convener may advert to one feature in the physical aspect of the island, viz., the extraordinary number of small lakes. When any of the hills are climbed, which afford even a tolerable view of the low grounds, it would almost seem that more of the island consists of lakes than of dry land. The cause of this feature probably is, that the general level of the island is so little above the sea, that the hollows occupied by these lakes can never be emptied. It is another striking feature, that most of these hollows lie in the same direction, viz., W.N.W. and E.S.E.

VII.—ISLAND OF CANNA.

The Convener when in the steamboat made the acquaintance of Mr William Bain, generally residing at Tiree, who takes contracts for erecting buildings in the Hebrides. He mentioned that he had lately built a new schoolhouse in Canna, an island situated near Rum. He told the Convener that he had found on the islet of Sanda, which forms the south side of Canna Harbour, blocks of a red sandstone which he made use of for the lintels and corners of the school doors and windows. The largest of these blocks was about 6 × 4 × 2 feet. He knew that these sandstone blocks differed from the rock of the island, which he described as a sort of blue slaty schist, ill-adapted for building. He recognised these red sandstone blocks as of the same nature as rocks in the island of Rum, which were good for building purposes, as he had quarried them for that purpose.

This statement by Mr Bain is confirmed by Macculloch. He says—" Sandy isle, like Canna, presents examples of a circumstance rare in the Western Islands, viz., loose fragments of a different rock from that of which it is formed, lying on the surface. There are large blocks of red sandstone somewhat rounded, and they are found in considerable abundance on the flat shores of both. 'The

rock of which they consist is that which forms so large a portion of Rum and of Skye.'" (Vol. i. p. 467.)

With reference to the conjecture that these red sandstone boulders in Sandy may have been transported from Rum or Skye, a probability of its correctness is afforded by the circumstance that the red sandstone rocks of Rum and Skye are situated on the sides of these islands facing Sandy and Canna.

VIII.—HARRIS.

1. At Rodel, the south end of Harris, there is a hill called Strondaval, 638 feet high. It is steep and rocky on all sides, especially the west and south. The Convener, under the guidance of Lord Dunmore's gamekeeper, scrambled along its south and east sides, and found that the smooth faces of the rocks all looked towards the W.N.W. On the east side of the hill there was an entire absence of smoothed rocks. That side had apparently been the lee side, not having been grated upon by the agency, whatever that was, which had smoothed the west side.

There were many boulders on the hill, chiefly angular; some pretty large, but none of any special interest.

2. At Borve, on the west coast, about half-way between Rodel and Tarbert, there is a remarkable accumulation of boulders on the side of the hill, sloping down to the sea. The general dip of the hill (which reaches a height of about 800 feet) is towards the west or west by north (magn.). The rocks are of gneiss, and present a series of beds, layers, or benches more or less horizontal, forming, as it were, a gigantic staircase along the hill face for about half a mile, several hundred feet high—all more or less covered by boulders. These benches of rock, in many places, show that they have been rounded by severe pressure from west by north. The boulders which lie on them give evidence of transport from the west.

Fig. 23 is intended, by a sectional view of the hill, to show the disposition of its rocks and the position of the boulders on them.

Fig. 24 gives a view of two boulders lying on a portion of the rocks forming the hill just mentioned. The position of both indicates blockage and stoppage on their east sides. Their own relative positions afford similar evidence.

3. Near Lach Castle valley, *i.e.*, about $1\frac{1}{2}$ mile south of it, and about 2 miles north of Borve, a striated rock was observed on the roadside. It had recently been uncovered by the removal of road materials. The rock was Silurian. It was well smoothed, and sloped gently to the west. The striæ were minute, but quite discernible, and running N.W. The rock was on the N.W. side of the hill called in the Admiralty chart Carron Hill, and close to the sea, which was all open toward the N.W. As Carron Hill, with a height of 786 feet, was to the S. and S.E., the presumption afforded by the surrounding land features was that the striating agent had come from the north.

4. Lach Castle bay and valley is shown on figs. 25 and 26. When the tide is out, the road between Borve and Tarbert crosses a sandy flat; but when the tide is up, the margin of the land is indicated by the dotted line. There is an immense accumulation of boulders on the S.E. side of the hill marked A, where Carron Hill, above referred to, is situated. The X on the fig. indicates the spot where the striated rock was observed.

If, when the sea stood say 1000 feet or more above its present level, boulders were brought by a current from the N.W., the facts observable in this Lach Castle valley could be explained.

In that case, the current would flow through the valley, pressing most upon the range of hills on the east side, and smoothing its rocks; whilst the rocks on the west side of the valley would remain rough. This is found to be the case on an examination of the two sides of the valley.

Icebergs or floe ice carrying boulders may have flowed up the valley from the north, discharging them chiefly on the hills along the east side of the valley. These hills bear on their sides and ridges numerous boulders, some of large size. Several of these were examined, and one or two gave indubitable proof, by their sites and by their own positions, that they had come from the north or N.W.

In the centre of the valley there is an elongated ridge (as shown on fig. 25, *l.c.*) which bears far more boulders than the depressed portions between it and the sides of the valley. There may be two ways of accounting for this. If the valley was originally of its present form, any ice borne on a current flowing through the valley

from the N.W. would strand more frequently on the central ridge and on the east side than elsewhere. If the valley was originally filled up to the level of the central ridge, the debris at its two sides must have been scoured out by the rivers now flowing through it; and in this case, whilst the boulders in these parts would gradually find their way to the channel of the rivers and to the sea, the central ridge would retain most of the boulders originally lodged on it.

On this ridge the smoothed rocks face due N. and not N.W. This deviation may be accounted for by the valley here being between two elevated ranges of hills running almost due north and south, which would cause the current to flow in a direction due south.

One of the boulders on this central ridge measured $16 \times 14 \times 12$ feet, = about 200 tons in weight.

It will be observed that on the S.E. side of A there is a large accumulation of boulders. These might have been floated there by an eddy occasioned by the projecting headland near A.

5. Almost $1\frac{1}{2}$ mile to the south of Tarbert, there are several large boulders, on the east side of the high road leading from Tarbert to Lach Castle. The Convener, on examining them, found them to be granite of a grey colour, whilst the rocks in the hills about them are gneiss.

These boulders being within half a mile of the sea, which is to the eastward, and being at a height of about 100 feet above the sea-level, it might have been presumed that they could have come from the eastward. But these boulders were on hill slopes facing the west; and as the slopes were steepish, it was not easy to understand why, if the boulders had come from the east, they had not rolled to the foot of the slopes. On the other hand, there were towards the west and north, ranges of hills, reaching to heights above the level of the boulders, viz., to about 200 or 300 feet. But towards the N.W., and at a distance of three-quarters of a mile, there was a gap or depression in the hill range; and, on applying the spirit-level, it was found that the depression was about the same level as the boulders, so that they might have come from that quarter by flotation, and been lodged on their present sites.

Fig. 27 is intended to represent what has just been described. B are the boulders, AAA a range of hills to the westward, with a gap in those at G, bearing N.W. from the boulders.

6. On the hills north of Tarbert there are many unmistakable signs of a N.W. current up to the highest level which the Convener was able to climb to, viz., 800 feet above the sea.

(*a.*) There are multitudes of knolls or bosses of rock, rounded and smoothed on their west sides, but rough on their east sides. There are none which show opposite markings.

(*b.*) There are many cases of boulders lying in such a way as to show that they had been stopped there in their progress eastward. One example is given in fig 28, where hard gneiss rocks had been rounded and smoothed from the westward, and a number of boulders —several of granite—were lying at the base of these rocks. A westerly current, if it smoothed the rocks, might have also brought the boulders.

(*c.*) At Avon Sue, or Fincastle, the handsome mansion-house of Mr Scott, banker, London, on the sea-shore about 11 miles west from Tarbert, the following observations were made:—

A little way up the hill, above the stables, a striated rock was met with. The smoothed rock sloped down towards the sea in a direction S.S.E. Three ruts on this smoothed surface when measured were found to be from 18 to 23 inches long, and about 2 inches wide Their direction was due east and west. The ruts were deepest and widest at the west end. In consequence of the direction in which the smoothed rock sloped, a N.W. current, coming against it, would be diverted into a direction nearly due east. The lines of the ruts in that direction ran up on the rock surface at an angle of about 8° or 10°.

On this hill slope there were several boulders whose position indicated clearly that they had come from the westward,—that is, from the sea. These proofs were the same as those explained in regard to other cases (see figs. 10 and 12), and therefore need not be repeated here.

IX.—ROAD FROM TARBERT TO STORNOWAY.

1. Where the road leaves the sea and strikes north there are enormous boulders, partly buried in drift, on the west flanks of the hills. This road reaches its summit level at about 650 feet —a distance of about 2 miles. The valley is narrow, between ranges of high hills on each side, and runs in a direction E.N.E.

As the summit was approached, it was observed that the boulders became less in size and fewer in number. This is quite intelligible if all the country had been under the sea, and a current flowing from the W.N.W., as this valley, on account of its direction, would have no great force of current in it, and the passage would be too narrow for much ice to pass through it.

At the summit level, a striated rock was observed, the striæ running W.S.W., *i.e.*, parallel with the general axis of the valley.

2. At *Ardvourlie* there is a *trainée* of boulders extending for at least half a mile, running in a direction east by north. On examining several clusters of boulders, it became apparent that the boulders had come not from the east but from the west.

Ardvourlie, to which this *trainée* reached, is close to the sea, viz., on a branch of Loch Seaforth, and the valley rises in a direction about west by south. In following with the eye the line of the *trainée*, it was seen to point towards a gap or depression in the range of hills at the west, distant about two miles. The Convener regretted very much that it was not in his power to follow this *trainée* and investigate the correctness of his conjecture—that the boulders may have come from the westward through the gap.

3. *Soval* is a shooting lodge of Sir James Matheson, on the road to Stornoway, and about 12 miles from it. To the east of Soval there is a rocky ridge, distant about half a mile, and at a height of about 220 feet above the sea.

On this rocky ridge the smooth faces of the rocks look towards the N.W. Indeed, in the whole of the district north of Ardvourlie, a distance of about 15 miles, this was the case with all the hills passed.

On the ridge just mentioned there was a boulder close upon its edge, which gave clear indication of a N.W. current. The rock forming the site of the boulder had been smoothed, and it sloped towards W.N.W. at an angle of from 20° to 25°. The boulder is in size $5\frac{1}{2} \times 3\frac{1}{2} \times 2$ ft. The longer axis of the boulder is W.N.W., and its sharpest end is towards the west. It is shown in fig. 29.

4. For 7 or 8 miles to the south of Stornoway, the district passed through by the high road from Tarbert, Ardvourlie, and Soval, consists of an extended plain covered by peat and coarse pasture. The height above the sea is from 200 to 230 feet. No hills or even

rocks are visible. There is an entire absence of boulders. From the banks of the small streams and the ditches by the side of the road, it was plain that sand and gravel lies in great beds immediately below the surface.

X.—NORTH PART OF THE LEWIS.

The Convener, through the courtesy of Mr M'Kay of Stornoway, Sir James Matheson's factor, was enabled to visit Lochs Ourn and Sheil, arms of the sea, to the south of Stornoway, on the east coast of Lewis. He landed from the steam yacht at both of these places, and had time to ascend several hills.

The rocks here, as at most other places, present their smooth faces to the W.N.W., their rough faces to the E.S.E.

At Loch Ourn, one of the boulders at a height of 200 feet above the sea (size $7 \times 5 \times 4$ feet) lay on the west side of the hill upon a rock surface sloping down to N.W. at an angle of 20°.

At Loch Sheil, at a height of 325 feet above the sea, the only boulder of any size ($10 \times 6 \times 4$ feet) was on a hill-side facing W.N.W., and on a rock surface sloping down in that direction at an angle of 15°; but 5 or 6 yards below the boulder, the slope down of the rock was 30°. The longer axis of the boulder pointed west by north.

The yacht steamed round the "Shiant" Islands, to afford an opportunity of seeing their magnificent basaltic columns. They are on a grander scale than those in Staffa, and exhibit remarkable curvatures. These islands are partly composed also of schists and stratified rocks, more susceptible of diluvial action than the hard basalt; and it was easy to see even from the deck of the steamer that a N.W. current had acted on them. Boulders also of considerable size were observed on the slopes facing the N.W.

The Convener regretted much that there was no opportunity of landing.

4. *Uig*, on the west coast of Lewis. On the hill near the parish church, about 186 feet above the sea, all the smoothed rocks front W.S.W., and on many rock surfaces sloping down towards west boulders were lying.

At two places, rocks were found with ruts and striæ. As at both, the general features were the same, one only may be illustrated by

a diagram, fig. 30, and on account of a peculiarity that the ruts crossed a fissure in the rocky surface.

The general surface of the smoothed rock at both places dipped due west at an angle of 12°, and looked out on the Atlantic Ocean, which was only a quarter of a mile distant. The direction of the ruts and striæ was the same at both places, viz., W.N.W., and rising up E.S.E. on the surface of the rock at an angle of about 10°. Probably owing to the obstruction which a current striking the rocky surface, dipping due west, would meet, a W.N.W. direction would be the result of a current from the N.W. At both places the ruts were wider and deeper at the west ends than at the east ends. One of the ruts was carefully measured, and showed at the west end a width of 2 inches and a depth of $\frac{3}{4}$ of an inch; at the east end a depth of $\frac{1}{8}$th of an inch; and there, the width ceased to be distinguishable.

The peculiarity before referred to was a small fault or fissure crossing the rocky surface as shown on the figure by the letters *a*, *b*, *c*. The fissure had caused, as it were, an upthrow of the rock, of about $\frac{3}{4}$ of an inch. Where the rut crossed the fissure, there was a slight deviation in the line of the rut, as shown in the figure. The hard pebble or stone which produced the rut, meeting with the obstruction caused by the upthrow, had been slightly diverted from its course, but it had eventually passed over the upthrow, breaking off the edge of the rock.

5. *Miavig* is a small hamlet situated on an arm of the sea, branching up from Loch Roag on the west coast of Lewis. About half a mile to the N.W. of Miavig a hill called "Dramamin Voltas" (height above sea 270 feet) rises above the general surface of the district, and has been the means of arresting a multitude of large boulders. They are clustered and piled over one another upon the north and west sides of the hill (see fig. 31). A few lie on the east side, a little way below, as if they had tumbled or slipped down from the top.

6. On the road from "Garry-na-hine" to Loch Carlowrie there are several objects of interest.

The hills are rocky. Their smoothed faces are all, as elsewhere, on and towards the west; their rough faces on and towards the east. There seems, however, to have been a slight change here in the direction of the current; for whilst at Breasdeit village the smoothed

rocks faced W.N.W., towards the north there was a gradual change to due west, and then ultimately at Carlowrie to W.S.W. and S.W. These deviations from the normal direction occur at low levels. Near the hill tops, at from 300 to 400 feet above the sea, there was little deviation from W.N.W.

The Convener examined a striated rock near the north end of Loch-na-Muilve mentioned by Mr James Geikie in his paper on the glacial phenomena of the Hebrides ("London Geological Society's Journal" for 1873, p. 537). As there are some points of interest on this rock not included in Mr Geikie's notice of it, a representation of the rock is given in fig. 32.

The rock dips down towards W.S.W. at an angle of about 30°. There are two portions of smoothed rock visible as shown in the figure—the space between them consisting of a stony clay, which probably lies on rock, though the rock is not visible. The part of the rock which is visible has evidently been smoothed by the passage over it of some material—such as the clay, of which a portion remains, containing pebbles and stones. The striæ and ruts are not all parallel. The lowest rise upwards across the rock at an angle of about 8°. The ruts in the upper portions of the rock surface rise up more quickly till at length, in the highest part, they rise at an angle of about 26°. Another feature is, that some of the ruts are deeper and wider at their west end than at their east end. The directions of the lowest ruts is N.W., of the highest W.N.W. If the general line of the current was W.N.W., the highest ruts would be more likely to indicate that direction than the lowest.

At Garry-na-hine, and also on the hills about two miles north of it, there are numerous cases of boulders on smoothed rock surfaces facing the west, the boulders being blocked at their S.E. ends by special obstructions, which were in each case distinctly observable.

7. Mr James Geikie refers to a water shed called "Beinn à Bhuna" on the road between Stornoway and "Garry-na-hine," where he says there are "smoothed and glistening domes of gneiss."

The Convener examined all the rocky knolls at the place referred to, on both sides of the summit level, which is about 400 feet above the sea. The smoothed surfaces are numerous, and particularly on the west side, where they face the N.W. The boulders are also more numerous on that side, and are generally on rock surfaces

dipping toward W.N.W. at angle of 10° or 12°. The longer axis of the boulders was mostly in the same direction.

8. About two miles east of "Garry-na-hine," a quarry on the road side at a height of about 160 feet above the sea had been opened for road materials. A tough strong clay covers the gneiss rocks here; and above the clay there are beds of gravel and sand, all evidently sea deposits.

9 The Convener visited the rocking stone on a hill 358 feet above the sea near Tolsta, about 12 miles to the N.E. of Stornoway. Resting on the gneiss rock, at a part of its base near the centre, it can be moved a few inches up and down by the hand only. It is about 18 feet long, 5 feet high, and 4 feet wide. Its longer axis points N.N.W. There is an opening among the hills in that direction, through which it might have been floated to its site; whilst towards the S.E. the hills reach to a greater height, and would prevent the boulder coming from that quarter. The boulder is extremely angular, and has undergone no rolling or pushing.

10. About five miles to the N.E. of Stornoway there are three hills called the Barvas Hills, each from 800 to 900 feet high.

The Convener examined the two eastmost hills, and found as follows:—

Both hills on the N. and especially the N.W. sides, present precipitous cliffs, and surfaces well rounded and smoothed; but no striæ were seen.

On the W. and S.W. sides of the middle hill, there are also a few smoothed rocks.

There are boulders on both hills on all sides, and up to nearly the top, but they are in greatest numbers on the N.W. sides.

On the middle hill, very near the top on its N.W. side, one of the smoothed rocks is traversed by a thick vein of quartz. The quartz also presented a smoothed surface. A specimen of it was brought away.

There was one boulder (6 × 5 × 4 feet) lying on a side of the middle hill facing N. by E. It might have come from the N.W., as in that direction there was no obstruction. From N.E., E., S.E., or S., it is difficult to suppose it could have come, on account of the interposition of the eastmost hill.

On the eastmost hill, at a height of 700 feet on the north side,

rocks were found smoothed from the N.W. A portion of smoothed quartz was found here also.

11. The Convener drove along the coast from Barvas village to Dalbeag, a distance of about 9 miles. He was unable to reach Dalbeag hills, about 2 miles farther on. He could see, however, that these hills presented large surfaces of bare rock on their west sides. He ascended one or two other hills of granite situated close to the sea, and up to a height of about 380 feet. On these hills he found abundance of smoothed rock surfaces sloping down to W.N.W. In one case only, the direction was somewhat abnormal, viz., west by north.

About half a mile to the east of Dalbeag farm-house there is a steepish bank facing the sea (which is due west, and only a quarter of a mile distant), surmounted by a cliff, as shown in fig. 33. The bank is about 50 feet high, and is covered by boulders and gravel. On the very top, viz., about 285 feet above the sea, the bare granite rock has been planed down and is occupied by a number of boulders. The only boulders which showed direction of transport indicated a N.W. direction.

At Sheabost, a place between Dalbeag and Barvas, notice was taken of a remarkable assemblage of gravel knolls on both sides of the road, but not forming a continuous kaim. These knolls were approximately elliptic in shape, the longer axis being about 50 or 100 yards, their breadth 10 or 12, and their height from 20 to 30 feet. Most of these gravel knolls have their longer axis running in nearly the same direction, viz., north and south. Large boulders lie on these knolls, and mostly on the west sides.

The boulders were in some places piled above one another. The uppermost showed from their position that they had come from the westward. The height of these knolls above the sea is about 130 feet. The distance from the sea-coast is about half a mile.

Nearer Barvas village there is a lake called Urraghay, on the west side of which there is a remarkable assemblage of large boulders, some of them granite, forming a sort of *trainée* running W.N.W. No rock is visible here. The ridge on which the boulders lie seems to be composed of coarse water-borne gravel. One of the largest boulders measured 12 × 10 × 5 feet. Its longer axis lay W.N.W. The uppermost boulders indicated transport from the N.W.

At Shadir, about 4 or 5 miles to the east of Barvas, there is a lake whose longer axis runs N.N.W.; its west bank has on it a considerable number of boulders, at a height of 240 feet above the sea.

At Galston farm and shooting-lodge there are some rocky cliffs, reaching to a height of 120 feet above the sea, bared as usual on the N.W. slopes, and having a few small boulders on these slopes.

A new school was built last year near Shadir, the stones for which consisted entirely of boulders extracted from under the peat. One of the masons employed on the school stated that many of the boulders consisted of Dalbeag granite, a variety which, on account of being better adapted for building than most of the rocks in the island, is well known to the native masons. One of the gateways to Stornoway castle was built of it. Dalbeag is distant from Shadir about 14 miles, and bears from Shadir west by south.

The scarcity of boulders in the district between Barvas and the Ness, when compared with their numbers almost everywhere else in the Lewis, may probably be accounted for by the absence of any ranges of hills in the north end of the island. If the sea stood 1000 feet or more above its present level, with a current in it from the N.W., and this current loaded with ice carrying boulders, it is to be expected that these ice floes, when obstructed in their progress by submarine rocks, would discharge their stony cargoes on these rocks, whilst in the districts where there were no submarine rocks, the current would flow on unimpeded.

12. In the neighbourhood of Stornoway there is the peninsula of Eye, on which the Convener found some smoothed rocks, and some boulders deserving of notice. Smoothed rocks occur to the west of Phabaill village, their smooth sides facing the west. Boulders of gneiss and of a hornblendic rock lie on the moor to the S.W. of the village. The rock *in situ* here is a species of conglomerate or breccia. The gneiss boulders most probably come from the Barvas hills, as they consist of gneiss. The Convener was told of a hornblendic rock, similar to that of the boulders, being on the N.W. shore of the Eye peninsula, but he had not time to go in search of it.

The Convener was informed by Henry Caunter, Esq., a gentleman of scientific knowledge resident at Stornoway, in the employment of

Sir James Matheson, of a sandstone boulder near the brickwork at Garabost, unlike any rock at present known in the Lewis; and he pointed out to the Convener some building stones brought from Loch Broom on the coast of Wester Ross, which he thought exactly resembled the rock composing the boulder.

As the occurrence of this sandstone boulder at Garabost is of importance, by its bearing on the question of transport, the Convener made a special inspection of it.

The Convener, having been introduced by Mr Caunter to M'Fadzyen, the manager of the brickwork, was taken by the latter to the boulder, and was informed by him that some years ago it had been partially blasted with gunpowder for building purposes. It had originally weighed about 8 or 9 tons, but the lower half still remained, showing its shape and position. The boulder was a coarse brown sandstone, full of quartz pebbles about the size of a small pea.

The boulder was on the side of a hill sloping towards the sea, on the N.W. side of the Eye peninsula, and facing the west. It was buried in a bed of gravelly clay, which had all the appearance of being a marine deposit, and it was within a mile's distance from Garabost brickwork. The height of the boulder above the sea was about 50 feet, and its distance from the sea about a quarter of a mile.

The Convener found on the surface of the same hill, sloping to the west, another sandstone boulder about the size of a man's head, exactly similar in composition.

The hill on the side of which these boulders were lying, rises up gently towards the S.E. to a height of about 160 feet above the sea.

Now it appears, from what Mr Caunter stated, that no sandstone rock, exactly similar to that of these boulders, had been seen in the Lewis; but, on the other hand, the geological formation or class of rocks to which these sandstone boulders belong, does exist in the Lewis. Dr Macculloch, in his geological map of the West Highlands, indicates, by its appropriate colour, this formation as occurring for many miles on the east coast of the island, near Stornoway.

The Convener had pointed out to him by Mr Caunter a long range of high cliffs along the shore, to the north and south of Stornoway, of a sandstone breccia or conglomerate, identical in composition with

a breccia or conglomerate occurring on the mainland, and which Dr Macculloch and Professor Nicol ("London Geological Society's Journal" for 1856, p. 37) concur in representing as "*the bottom beds*" of the great sandstone formation which lines the north-west coast of Scotland, and which constitutes the entire mass of a number of small islands lying off the coast, extending from Cape Wrath to Skye, a distance of about 100 miles. Dr Macculloch mentions having observed a similar conglomerate on the west side of the Lewis. ("Western Islands," vol. i. p. 196.)

These breccia sandstone cliffs extend along the east coast of Lewis for about 15 miles. Referring to them, Mr James Geikie ("London Geological Society's Journal" for 1873, p. 534) says that "red sandstone and conglomerate of Cambrian age cover a portion of the Eye peninsula and the shores of Stornoway harbour at Arnish point. The same deposits are continued north as far as Gres."—Gres is about 15 miles to the north of Arnish.

This sandstone formation is not confined to the coast. It extends some distance inland, though how far has not been ascertained. Mr Caunter showed to the Convener a bed of the breccia in the channel of a stream which runs through his garden on the north side of Stornoway. Mr Geikie, in his paper before referred to, suggests that "red sandstone may occupy the sea-bottom at no great distance from Cellar Head, and hence we are not compelled to suppose that these sandstone fragments have travelled from the mainland" (p. 539). The "sandstone fragments" here alluded to by Mr Geikie, are "red sandstone boulders, lying in the fields, which we found at the Butt" (the northern extremity of Lewis), and also on "the sea-beach at Barabhais" (a place about 20 miles from the Butt, on the west coast). Cellar Head is a point on the east coast of Lewis, 5 or 6 miles south from "the Butt."

Mr Caunter told the Convener that he had seen the sandstone boulders on the shore between the Butt of Lewis and Ness, and that they occur there inland up to a height of 300 feet.

Now, a presumption arises, from the number of these sandstone boulders at and near the Butt, that there must be in that district rock *in situ* of the same nature. The Convener regretted having been prevented searching the coast and fields between the Butt and Barvas, to examine these boulders and see if any sandstone rocks

occurred there on the shore. He, however, saw Mr M'Farquhar, the intelligent ground officer at Barvas, and learnt from him that about a mile or more to the west of the mouth of the Barvas river, where it flows into the sea, there are rocks which seemed to him to have the appearance of sandstone rocks, but that he was not competent to judge of such a matter.

In these circumstances, the presumption is that the sandstone boulder at Garabost came, like all the other boulders in the Lewis, from the westward, and not from the mainland of Ross-shire.

13. The Convener (IX., art. 4) referred to the flatness of the district to the south of Stornoway. Between Stornoway and Barvas and also both towards Dalbeag and the Butt of Lewis, the island presents similar tracts of flatness. The general height above the sea is much the same over both districts, viz., from 200 to 300 feet. The deposits forming these extensive plains consist of great sheets of gravel, sand, and stony clay,—the clay being generally the lowest bed. In these flat districts, there is a remarkable scarcity of boulders when compared with their number to the south, and these few are much below the average size.

A great many sections of these deposits were examined for sea shells;—but the only place where shells were seen by the Convener was at the brickwork of Garabost above referred to. These shells—chiefly the *Cardium edule*—have long been an object of interest, and were examined by the late Dr John Davy of London, as well as by Sir Charles W. Thomson and Dr Carpenter. At one time they were thought to be arctic; but the latest opinion is, that they are of the type now existing in the adjoining sea.

Mr James Geikie gives an account of this Garabost deposit in the memoir read by him before the London Geological Society in April 1878. But his account is founded, as he says, chiefly on information supplied by Mr Caunter, whose letter he quotes. As the Convener made a careful examination of this clay-bed, he gives, with the aid of fig. 34, the following description of it:—*a*, is gneiss rock; *b*, is coarse shingle; *c*, is the bed of clay now worked; and *d*, is sand covering the clay.

The Convener picked up fragments of the shells from the bed *b*, as also several well-rounded boulders of gneiss, about the size of a child's head.

The manager of the brickwork pointed out how the upper part of the clay-bed appeared to have been scooped out in some parts; the hollow thus made being filled with sand and mud. The bottom of the clay-bed was not sufficiently exposed when the Convener visited the place, so as to show the bed of shingle; but there was a heap of coarse gravel near the work, which the manager stated had come from the bottom of the clay-bed. The Convener had also explained to him the vegetable remains said to have been found in the upper part of the clay, to which Mr Geikie alludes, as supposed by Mr Caunter to have been "*common sea tangle;*" but of this the Convener saw no specimen.

Mr Geikie mentions that the clay-bed at Garabost is "in all probability of the same, or approximately the same, age as the similar beds in the north of the island" (*Lond. Geol. Soc. Quarterly Journal*, vol. xxxiv. p. 827).

The Convener made an attempt to reach the north of the island, to see those shelly clay-beds referred to by Mr Geikie; but, from want of time, he failed to get so far north. He therefore may be permitted to refer to Mr Geikie's account of these beds, and to quote one or two passages:

"At Port of Ness the boulder clay contains patches of sand. But the most remarkable feature is the presence of broken *arctic and boreal shells*, which occur in an irregular manner through the mass. The *upper surface of the boulder clay is denuded;* a character better shown in fig. 37, which is taken from the same locality. The stratified beds contain *shells, most of which are in a fragmentary state, but some perfect specimens may be detected.* They belong to arctic and northern species." Another place is mentioned where "the beds consist of an upper series of sand and gravel deposits, more or less separated from an underlying deposit of imperfectly laminated dark blue and grey clay, and silt or mud. *Shells occur in both.*" ("Great Ice Age," 2d edition, p. 170.)

These shelly beds of boulder clay, according to Mr Geikie, extend over a considerable tract in the north of Lewis. He states, p. 183, "*The shelly tills in the sea cliffs near the Butt stretch across the island from shore to shore,* a distance of two miles or thereabout, forming a narrow belt of low ground, which does not rise more

than 90 feet or so above the sea. The deposits extend for somewhat less than a mile along the east coast, but on the *west* side of the island one can trace them for a distance of *three miles.*"

In connection with this northern part of the island, it is proper to notice several remarkable lines of kaims or gravel ridges and knolls. The Convener's attention was first called to these by Mr Mackay (Sir James Matheson's commissioner), who pointed them out from the high road between Stornoway and Barvas, as a feature of the district he had seen nowhere else. The Convener observed these ridges on both sides of the road, and a few days afterwards he had an opportunity of walking along one of them to the north of the Barvas hills. The ridges consist of gravel and sand, and reach a height of 30 to 50 feet above the adjoining level ground, from which they are the more easily distinguished by the uniformly green colour of the herbage on them, whereas the flat district they traverse is covered with brown peat and moss. Each of these gravelly ridges is continuous for more than half a mile, and they deviate very little from one direction, which is about W.N.W. (magn.) When on the top of the Barvas hills, the Convener was able to trace the line of one of these kaims, for at least two miles, running in a direction N.W. and S.E. It passes Loch Scarabhat at its south end. In several parts of their course, boulders occur on the ridges and sides of these kaims. At one place, two or three miles north of the Barvas hills, to which the Convener was conducted by Mr M'Iver, an intelligent gamekeeper, well acquainted with the district, he found the kaim expanded into a number of grassy knolls, much resorted to in summer for the good pasturage they afford to cows. These knolls were, in some spots, well covered with boulders : the highest knolls being those where the boulders are most numerous. The boulders were sometimes on the east sides of the knolls, but more frequently on the west sides. At two places, the boulders were heaped and piled on one another. The Convener attempted to elicit from their relative positions, the quarter from which they had come. Most of the boulders showed unmistakably that they had come from the N.W., but some also from W.S.W. One boulder indicated transport from N.N.E.

An old man who was looking after the cows at this shieling noticing the attention paid by us to the boulders, volunteered to

mention that robbers used to live in the recesses among the boulders. The Convener's man-servant crept into one of the recesses pointed out, which was so large as not only to admit him, but conceal him when in it from our view.

Another observation by the Convener in connection with this district may be mentioned. On the north side of the middle Barvas hill there is a deep hollow, like a huge trench, close to and parallel with the northern contour of the hill, suggesting the idea, that when the country was submerged, an oceanic current from the N.W. striking on the hill may have scooped out the drift forming the sea-bottom at this place.

14. The Convener was as much impressed as Mr Geikie appears to have been with the number and direction of lakes in the Lewis. In his "Great Ice Age" (2d ed., p. 168), under the head of "Lakes occupying hollows in the till or other superficial deposits," Mr Geikie states,—"They rest sometimes in the hollows between banks of till, and not unfrequently in cup-shaped depressions of sand and gravel. The most considerable assemblage of these lakes of which I know, is in the Island of Lewis; the low lying tracts of which are literally peppered with lakelets. Not a few of these belong to the drift-dammed series. But hundreds of them appear to rest in hollows of the till, their longer axis pointing by N.W. and S.E." The Convener remembers that when on the road from Stornoway to Garry-na-hine, he stopped the carriage to count the lakes spread out before him. They were 17 in number—though seen from a point only about 300 feet above the sea. To the north and north-east of the Barvas hills the lakes are even more numerous.

The Convener also concurs with Mr Geikie in his remarks (*Lond. Geol. Soc. Journal*, vol. xxix. p. 541) that, "with one exception, all the longest and most considerable lakes range in a direction from S.E. to N.W." "They extend in long lines, often for a mile or two, with an insignificant breadth."

When Mr Geikie proceeds to suggest a cause for the formation of these lakes, and for their persistency in a N.W. and S.E. direction, the Convener is unable to concur. He says—"When the ice that swept across the Lewis finally vanished, it left as marks of its power not only rounded and fluted hill tops, but hollows scooped out in the solid gneiss. The till that accumulated below the ice was also

at the same time found arranged in long parallel banks, running in the exact direction followed by the ice striæ and *roches moutonnees.* The arrangement of the till into long parallel mounds is a feature with which I have long been familiar." "The N.W. and S.E. lakes then rest in true rock basins, and also in hollows between parallel banks formed wholly of till, or partly of rock and till" (page 542).

The Convener walked along the banks of many of the lakes in the northern part of the Lewis. He does not remember having seen much or indeed any rock on those banks. At all events, the banks certainly in most cases consist of gravel and till, forming "*long parallel mounds,*" as stated by Mr Geikie. On some of the heights, as at Bein-na-Bhuna, there are domes of smoothed rock. But because they are round and smooth, the Convener does not admit that they thereby prove glacier agency. The main facts mentioned by Mr Geikie the Convener quite admits, viz., that most of the lakes are "occupying hollows in the till and other superficial deposits"—that the axis of these hollows is, generally speaking, N.W. and S.E.—and that this also is the direction of the ruts and flutings on smoothed rocks. Mr Geikie assumes that these lake hollows, and these ruts and flutings, were made by one and the same agent, viz., ice, which came from the S.E. The Convener, on the other hand, ventures to suggest that the ruts and flutings may have been made by an agent which came from the opposite direction, viz., the N.W.; and that this agent may have been an oceanic current loaded with ice, which ploughed through the old sea-bottom, pushing hard stones over submarine rocks, which were thereby smoothed and striated.

There is one general view put forth by Mr Geikie with which the Convener agrees. Mr Geikie, after traversing the whole of the Outer Hebrides, from the Butt of Lewis to Barra Head, has formed an opinion that the phenomena of smoothed and striated rocks and boulders in all these islands can be best explained by one agent, which embraced and spread over the whole, and reached up to at least 1600 feet above the present sea-level. The Convener concurs in that view. In all the Hebrides which the Convener was able to visit he found a remarkable agreement in the direction of boulder transport and of rock striations, and in the disposition of superficial deposits. This agreement does certainly suggest the agency of some general agent embracing all the islands. The only

question is, What was this agent? Was it a sheet of ice from Ross-shire, crossing the deep channels of the Great and Little Minch and flowing from the S.E. with a breadth of 120 miles? Or was it an ice-loaded oceanic current from the N.W. when the sea was, say, 2000 feet above its present level?

As reference has been made to the low-lying level plains occurring in the Lewis, and to the beds of sea-shells in the till, it may not be deemed irrelevant to mention that there are on many parts horizontal terraces, bounded by cliffs which seem to indicate old sea-margins. Along the east coast, from Loch Seaforth to Stornoway, there are cliffs at heights of 11, 40, 81, 180, and 220 feet above the sea. The road from Stornoway to Garry-na-hine, for some miles, passes through a valley exhibiting a sea cliff at a height of from 210 to 220 feet. The valley through which the River Barvas flows to the sea, exhibits distinctly two terraces with cliffs, one 40 feet and the other 170 feet, above the sea.

The theory of an ice-sheet from Ross-shire overspreading all the Outer Hebrides is too large a question to be discussed in this Report. But as having an important bearing on the question, the Convener may advert to the way in which the boulders are distributed in these islands. It has been already remarked that boulders are scanty on the east coasts of those islands, and in particular on the low-lying districts in the north of Lewis. It may be supposed that it is only natural that the boulders should be most abundant on the west coasts, as the highest hills are there. But it does not follow that the boulders, because they rest on these hills, were generated there. For example, the large boulder on the west flank of Dun-Ii in Iona, the numberless boulders on the sea cliffs on the west coasts of Tiree, Coll, Barra, Uist, Harris, and the Lewis, must have come from the westward, and been stranded on the first islands, or submarine rocks or shoals, which impeded the farther progress of the ice which brought them. On that theory, it would not be difficult to explain why the boulders, whilst abundant on the mountains which fringe the west coast of the Hebrides, should be generally absent from the eastern and northern portions of the Lewis, where there are no hills, or any other obstruction to the ice in a sea, if one prevailed, about 1000 feet above the present level.

If glaciers ever existed among the hills of Harris, their effects

must have been confined to their own valleys. Though Mr James Geikie, in his valuable Memoir on the Glaciation of the Hebrides, assumes that there were such glaciers, he not only admits but maintains, that "the ice, with which the mountain valleys of Harris and the south were filled, *had no share whatever in the glaciation of the northern part of the island*, extending from the base of the mountains to the Butt, a distance of not less than 35 or 40 miles. Where, then, did the ice come from which overflowed this by far the largest part of the island? There is only one place whence it could have come,—the *mainland*." Mr Geikie "contends that it was amongst" the "mountains of Wester Ross, fringing the borders of the Minch, that the glaciers which overflowed the Lewis were nourished" ("Lond. Geol. Soc. Journal" for 1873, p. 544). In his second Memoir, read in April 1878, Mr Geikie extends this theory to all the Outer Hebrides, maintaining "that *the whole of the Long Island, from the Butt of Lewis to Barra Head*, has been overflowed from the Minch by ice that moved outwards from the inner islands and the *mainland*" (p. 861.) If this had been the case, one would have expected to find boulders chiefly on the *east* coasts of the Hebrides, and few on the *west* coasts. But the facts are entirely the other way. Not only is it on the hills of the *west* coasts that boulders most abound, and are largest in size; but it is also on the slopes of the hills facing the Atlantic that these boulders are mostly seated. On the hills of the east coast next the Minch, the boulders are few and small, and they are chiefly on the west flanks of these hills, and therefore unlikely to have come across the Minch.

XI.—OBAN AND ITS NEIGHBOURHOOD.

In the immediate neighbourhood of this town, there are some facts of interest.

(1.) There, as among the Hebrides, the smoothed rocks on the hills above Oban face the N.W.

A little above the Craig-Ard Hotel, there is a fissure in the hills from 12 to 20 yards wide, and running due north and south for 200 yards, at an elevation above the sea of about 180 feet. The fissure has apparently been occupied by a trap dyke, which, from the sea or other natural agencies, has decayed and disappeared. The walls of

the fissure are from 12 to 20 feet in height. The east wall of the fissure presents numerous portions of rock well rounded and smooth. The west wall is rough and jagged. These appearances suggest the action of a current which has grated on the east wall and not on the west wall.

As this is a case exactly similar to that referred to as occurring in Barra, and shown by figure 11, it is unnecessary to give another diagram.

(2.) Not far from the foregoing spot there is a coarse-grained conglomerate rock. It is at the junction of three roads. It is the same species of rock which forms what is called the Dogstone on the avenue to Dunolly, at Oban. The included boulders and pebbles are well rounded, and consist of hard gneiss and quartzite.

Fig. 35 represents a portion of this conglomerate rock,—about 20 feet across—viz., between east and west, and 5 feet between north and south. On the side of the rock facing the N.W. the hard pebbles and boulders in the rock have all been ground down to an even surface; whilst on the side facing the S.E. the pebbles and boulders retain their original shapes, and stand up above the clay matrix of the rock.

(3.) About 6½ miles from Oban, at a place called "Lailt," there is a boulder of considerable size called "Clach-a-Currail" or Perched-up Boulder. Its height is 14 feet, and its girth about the middle 29 feet. Its situation is extremely critical, being on the edge of a precipice which goes down at an angle of about 75° for 50 feet. The rock of the boulder is peculiar,—a dark chocolate-coloured porphyry. No rock of that description elsewhere could the Convener hear of.

How the boulder got into the site it now occupies, or from what quarter it came, it would be difficult to say. Judging from the position of the boulder, the presumption is that it came from the S.E., *i.e.*, down the valley leading up to Loch Awe. But it may have come from the N.W., as in that direction there is a valley by which it could have floated to its present position.

About half a mile to the N.E. of this boulder there are fragments of what had been a much larger boulder, which a year ago had been blown up for building purposes. It was a coarse granite, whilst all the rocks in the district are gneiss. Its position suggested trans-

port from the S. or S.W. as the most probable quarter, though the N.W. was not impossible.

Most of the small hills in this neighbourhood are bare on the N.W., and are smoothed on that side only.

(4.) The Convener paid a visit to a glen called Glenlonnan, the mouth of which comes down to Loch Etive near Taynuilt. He had been told of there being several large boulders on a hill called Bein Glas in that glen, about 1700 feet high. This is the glen referred to in the last Report of the Committee, page 12 and section 5. He was guided to these boulders by Mr Clerk, a son of the tenant of the farm of Duntonichan, of which Bein Glas forms part. In ascending the north flank of the hill, it was observed that the smoothed rocks here as elsewhere distinctly sloped down towards the N.W., and that rounded boulders were often on these rocks. The rock of the hill was gneiss, and most of the boulders were also gneiss; but there were also some of granite, a few of mica slate, and a very small one of quartzite. The largest granite boulder passed measured $6\frac{1}{2} \times 4 \times 3$ feet. The longer axis pointed N.N.W. The rocky surface on which it rested dipped due north.

When a height of 1619 feet was reached, which was near the top of the hill, it created some surprise to find that there were smoothed rocks facing the *south*, besides others facing the north.

Several large boulders were found occupying positions on slopes facing the south. One of these was a well-rounded grey granite, at a height of 1573 feet.

At a height of 1637 feet there was a boulder, $8 \times 5 \times 5$ feet, very angular. It was a dark purple claystone, in appearance similar to the boulder, shortly above mentioned, seen at Lailt. It was resting on a shelf of gravel, but the general slope of the hill was exceedingly steep, viz., forming an angle of about 35°, sloping down S.E.

Judging by the position of these boulders, and the steepness of the hillside facing the S.E. or the S.S.E. which they occupied, the presumption is, that they had come from that direction. The rocks of the hill at this spot are also smoothed in that direction. Towards the south there are high mountains in the distance.

Another grey granite boulder, $3 \times 3 \times 2$ feet, was found at a height of 1645 feet on a rocky slope, less steep, but still facing the south.

At a height of 1683 feet, about 11 feet below the summit, smoothed rocks were still found sloping gently towards the south.

On descending the hill towards the north, by a more westerly path than that followed in ascending, it was observed that, at a height of 1554 feet, the smoothed rocks faced the north.

Some of the boulders met with on the descent were of the same dark purple porphyry seen at Lailt.

(5.) On reaching Loch Etive, the Convener visited the Airde point, a projecting cape or headland on the west side of the loch. At this point there were many well-smoothed rocks up to a height of 276 feet above the sea, and facing up the glen towards Loch Awe. There can be no doubt that these rocks had been smoothed by glacier action. On this Airde point there were numerous boulders, chiefly of grey granite. They may have been pushed down the glen by a glacier;—indeed it seemed the most probable supposition. But they might have been floated up from the N.W. None of the boulders seen were in such a position as to indicate with any certainty the quarter from which they had come.

It may be added that the rocks on the south shore of Loch Etive, as far down as Connel ferry, and even lower, show smoothings all facing up toward the head of the loch, suggesting glacier action from the upper part of the valley.

(6.) In the Fourth Report by the Committee (p. 11), reference was made to boulders observed in the Island of *Kerrera*, at the north end. This year the Convener had an opportunity of examining the boulders in the middle of the island, where it is traversed by the high road leading from Ballimore farm to the ferry for Mull on the west side of the island, called "Bal-na-Bok."

On his way across the Island, he had pointed out to him by Mr M'Dougal, tenant of Ballimore farm, three or four well-rounded boulders of a coarse granite, having a red tinge, imparted from the felspar crystals. They were from 2 to 3 feet in diameter. Mr M'Dougal stated that there was no granite rock in Kerrera which he knew of; and that the nearest place where he had heard that granite of that kind was worked was at Morven, about 12 miles across the sea to the north. He was sure it was not the same as any he had

seen in Mull. He referred the Convener to Mr John M'Dougal, builder, Oban, as one who had a practical knowledge of granite rocks.

On the hill sides facing the north and west, the Convener observed here and there several boulders. They were all mostly of the same coarse-grained granite. There was one of a purple claystone porphyry. When he reached "Bal-na-Bok," he passed several boulders of coarse-grained granite, and one block of mica schist, which had been hollowed out for some domestic use. He learnt from the old ferryman (M'Kinnon) and his daughter, that there were boulders of granite about 4 feet high at or near the tops of the hills to the south of the ferry. Rainy weather prevented access to them.

On returning to Oban, the Convener called on John M'Dougal, the builder, and showed to him specimens of the granite boulders which he had found in Kerrera. On asking him if he knew where there were any *rocks* in the hills of a similar description, he said that he knew of two places,—one to the south of Ben Cruachan, the other in Morven,—and that he thought the Morven rock more nearly resembled the specimens shown.

He was not acquainted with any granite exactly similar existing in the island of Mull. He knew very well the red granite of the Ross of Mull; and he added that, at a place which he called the "North Bay of Mull," there was a grey-coloured granite, much lighter in colour than that in Loch Etive.

In these circumstances, it is still matter of doubt from what quarter these red granite boulders in Kerrera were transported.

(7.) The Convener next day paid a short visit to Easdale, and was conducted by Mr John Clerk, blacksmith, Kilbride, to several places in the neighbourhood, for an inspection of boulders which had been reported by him in one of the circulars to this Committee. The district visited was that traversed by the high road to Clachan Bridge, situated about 3 miles to the N.N.E. of Easdale. The rocks of this district are all a blue clay slate, extensively quarried for roofing. Most of the boulders examined were of grey granite, but their position did not indicate clearly the quarter from which they came. They probably came from the north or west, as there was less in these directions to obstruct them in their transport than in any other direction.

To the south of Easdale, there is an extensive terrace along the coast, about 18 or 20 feet above high-water mark, and some hundreds of yards wide, bounded by a range of high rocky cliffs, with caves which evidently had been formerly reached and undermined by sea waves. On this terrace lay a cluster of boulders, several of them of grey-coloured granite, which most probably had been lodged where they now lie by ice floating from the north, and arrested in its further progress south by these rocky cliffs. Several boulders were noticed by the Convener at and near the tops of these cliffs, which he regretted not having had time to inspect.

Mr Clerk informed him that on the hill immediately to the east of Easdale, about 1200 feet in height, there were near the top several large boulders, which he hoped would be examined at some future period.

Whilst it seemed probable that these Easdale grey granite boulders came from the north, there was one large claystone boulder, of a purple colour, which, from its position, seemed to the Convener to have come from the south. Its size was 12 × 7 × 6 feet. It lay on the shore near Clachan Bridge. On asking Mr Clerk if he knew of any rock *in situ* similar to that of the boulder, he pointed to a hill about a mile distant, situated to the south.

The Convener has referred to several boulders of a purple-coloured claystone, very similar to this one, as having been seen by him at "Lailt" (3) above, and "Duntonichan" (4) above, which also suggested transport from the hills to the south.

(8.) The Convener on 1st July ascended Ben Cruachan from Inverawe, up as far as 2725 feet, and made the following observations:—

Until a level above the sea was reached of about 1330 feet, few boulders were met with. At and above that height the boulders were numerous, and many of them of large size. They were most numerous on the N.W. shoulder of the hill. In that direction there was the least obstruction to transport. Due N., N.E., E., S.E., S.W., due W., there were hills of formidable height which would obstruct. Towards the W.N.W. and N.W. there were only the hills in Mull and Ardnamurchan, distant from 30 to 40 miles.

The possibility of transport by a glacier down from Loch Awe or

Dalmally, was not overlooked. But if any glacier had filled the valley to the height of 1330 feet, bringing down boulders, these boulders would have much more probably been lodged on the hill to the north of Cruachan, called Daranish, opposite to Bonawe, where there is now a great quarry of granite. But on that hill, at least on the side opposite to and looking up towards Loch Awe, only a few boulders were discernible.

On the other hand, if boulders were brought by a N.W. current, the part of Cruachan which would be first and chiefly struck would be its N.W. shoulder, where the boulders now lie in great heaps, whilst that part of Daranish hill, which faces about south by west, would be sheltered from the current.

The following boulders of considerable size indicated by their position that they probably had come from the N.W.:—

One at a height of 1890 feet, resting on gravel, $15 \times 9 \times 5$ feet.

Another at a height of 1943 feet. It was 13 feet long $\times$ 7 feet high. Its longer axis bore N.W. by W. At its west end, its width was 2 feet, at its east end 5 feet. It also lay on gravel and small boulders.

At a height of 2194 feet, the rocks of the hill—a coarse reddish granite—presented extensive smoothings facing W. by N.

At a height of 2386 feet, there was a boulder $7 \times 6 \times 5$ feet, evidently blocked on its E.S.E. side by the rock of the hill.

At a height of 2428 feet, a grey granite boulder was found near a summit level, where the rock—a red or yellow felspar—showed smoothings from the N.W.

The hill to which these observations apply was not one of the central peaks of Cruachan, but situated to the N.W. This hill is known in Gaelic by a name which in English means "hill of the horse heel." Its top was not reached by about 100 feet. Boulders were, however, descried on it reaching to the very top.

Descent from this hill was made on the side next to Cruachan, *i.e.*, on its S.E. and S. side. No smoothed rocks were observed on these sides, and but few boulders.

If a glacier descended the valley from Loch Awe, grating on Cruachan, it is natural to suppose that the rocks on these flanks of Cruachan would have shown some smoothings. There is a

vertical cliff of rock, about 60 feet above the River Awe, on Cruachan, which did suggest glacier friction; and at a height of 334 feet above the sea, above Inverawe, the Convener found rocks which seemed to have been smoothed from the W.S.W. But above that height the rocks presented smoothings successively from N.W. by N., from N.N.W. and W.N.W.,—the W.N.W. being in the highest parts of the hill, apparently the most persistent direction.

(9.) The Convener afterwards proceeded to the head of Loch Etive in a steamboat, and then travelled by coach nine or ten miles to the head of Glen Etive, to a height of about 600 feet above the sea. The whole of this valley has at one time been filled with gravel and boulders of grey granite. A great part of this mass of drift had apparently been scoured out by the action of the numerous streams which descend from the high steep mountains on each side of the glen. Terraces were occasionally visible on the south side of the glen, up to a height of about 500 feet above the present channel of the river, consisting of clay, gravel, and sand, which may have been the bottom of an estuary in former times.

XII.—LOCH CRERAN.

The Convener paid a visit to Loch Creran, having last year seen that there were there more objects of interest than he had then been able to overtake.

At the mouth of Loch Creran, where it joins the Linnhe Loch, the rocks are all smoothed when they face the W.N.W. at about 70 feet above the sea, and also at Craigan Ferry. But about a mile higher up the loch, the smoothed rocks face W.S.W., at a height of about 80 feet above the sea.

Near the sea-level, the smoothing of the rocks seemed attributable to the action of some force moving down the valley, whilst rocks at a higher level, say 100 feet and more above the sea, grinding from the N.W.—*i.e.*, *up* the valley—seemed undoubted.

On going up the glen towards Carroban hill, notice was taken of a *trainée* of boulders which appeared to go over a summit level to the east of that hill. The boulders are all of a dark-coloured fine-grained granite, and are apparently the same as the Fasnacloich and Appin boulders referred to in last year's Report. Mr Hall, the intelligent tenant of Fasnacloich, who from boyhood has lived in

the district, mentioned that the *trainée* of boulders could be followed for some distance over the hill, towards Glen Etive and Glencoe.

A very large boulder exists in a *cul de sac* formed by lofty hills near Carphin at the head of the valley. It goes by the name of the Ardshiel boulder, in consequence of having been made use of by the proprietor of Ardshiel for concealment in the time of the Rebellion. This boulder is $40 \times 27 \times 15$ feet = about 1000 tons.

A fissure exists through the middle of it, which is large enough to allow of a man getting into it from the top, where, however, the fissure is not discoverable at any distance in consequence of beech-wood growing on it. This boulder is, in composition of rock, the same as all the rest of the boulders in the glen, and it has undoubtedly been floated like the rest, up the glen. It is blocked on its west side by a large mass of rock, which stopped its further progress up the glen. Its height above the sea is 506 feet. On account of its weight, the ice which rafted it was probably so deep in the water that it could not get over the summit level by which smaller boulders passed to the east of Carroban hill.

The boulders in Glen Creran are mostly on coarse gravel. At one place above Salar House, there is a cluster of boulders on a rocky knoll.

The summit level on the east side of Carroban hill is about 800 feet above the sea. If the sea, when these boulders were being transported, stood, say 2000 feet higher than at present, any current from the N.W. would flow through and over that Carroban pass. On that supposition, it would not be difficult to account for the *trainée* of boulders in Glen Creran and for the presence of the gigantic boulder in the *cul de sac* at Carphin.

If Robert Hall's statement that the black granite boulders are traceable up the Carroban valley, and over the summit level which separates Glen Creran from Glen Etive, some of these boulders should be found in the upper parts of Glen Etive. As the Convener passed up that valley on the coach which travels between Loch Etive and Glencoe, he observed several boulders on the moors, near the road, exceedingly like the Loch Creran boulders; but he had no opportunity of particularly examining them.

With the view of so far testing the statement by Hall, the Con-

vener at a subsequent date walked across the moors from Ballachulish Hotel to Carroban hill, to see if there were any black granite boulders in that quarter. He fell in with several at a height of about 800 feet above the sea, and he saw that boulders were thickly spread up the valley to the summit level, but unfortunately, he was prevented reaching them for examination on account of distance.

It is worthy of remark, however, that in this side valley, running up from Glen Creran, grey granite boulders are also numerous, whilst in Glen Creran itself there are none. Now, at this place the rocks *in situ* are slate rocks. The nearest mountain of grey granite is situated to the N.W., about four miles distant. A N.W. current would bring fragments of rock to the place where the Convener found them, but not to Glen Creran, at least to its lower parts.

XIII.—GLENCOE.

This valley is quite as remarkable for objects of geological interest, as for picturesque scenery and for stirring historical deeds.

It contains many phenomena of extreme importance, connected with the transport of boulders and the grinding down of rocks.

The Convener began his examination of the glen, at "Alt na Fay," a place about 17 miles distant from Ballachulish Hotel, and about 3 miles distant from King's House.

Having introduced himself to John Matheson, a young shepherd residing at "Alt na Fay," the Convener obtained his services as a guide for some distance down the glen.

The first place visited was a gravel knoll, near Matheson's house, having on it a cluster of boulders, the largest and uppermost being well seen from the coach road. Its size is 8 × 4 × 4 ft., and it consists of a hard clay slate similar to that of the neighbouring hills in the north. Underneath this boulder, there was one of smaller size, consisting of a red felspar, of which, as Matheson informed the Convener, there was also rock in the hills. But there were no hills within a quarter of a mile of this gravel knoll, and no cliffs from which the boulders on it could have fallen. The top of the knoll was about 30 feet above its base, and was of a somewhat conical shape. An examination of its *side*, showed numerous boulders, half buried in the gravel composing it. On the *west* side, there were from

twenty to thirty boulders, on the *east* side only one or two. The greatest number consisted of grey granite—of which rock, however, as Matheson assured the Convener, there was none in Glencoe; the nearest being, as he said, on the shore at Ballachulish Hotel, at the mouth of the Glen, and farther westward towards Duror.

Matheson then conducted the Convener *down* the valley on the north side to some larger boulders. Several were pointed out from 10 to 12 feet long, at heights of 1200 to 1400 feet above the sea. These also were of grey granite, their longer axis being about east and west, or parallel with the direction of the glen, at this place, and about 400 feet above the bottom of the glen.

About 50 feet above these grey granite boulders, smoothed rocks were observed. There were no striæ; but the smoothing seemed due to a frictional agent which had come *down* the glen.

On the same (north) side of the valley, the Convener had pointed out to him by Matheson, at one or two places, about 1183 feet above the sea, a mass of conglomerate rock *in situ*, similar, as he said, to the "Dog-stone" at Oban. The Convener observed that two fragments had been detached from the rock, and been formed into boulders. One was on the slope of the hill, about 50 yards *west* of the parent rock, and 30 feet below it in level; the other of these boulders, and larger in size, was resting on the schist rock of the hill, about 200 yards *west* of the parent rock, and about 45 feet below it in level. These observations indicated that some agent had here been *moving down the glen*, and had both broken off and transported portions of the conglomerate rock.

On the other hand, there is a cliff of this conglomerate rock which holds in a cleft of it a grey granite boulder, and in a position which shows that *it* had *come up the glen* from the west. Fig. 36 A represents this boulder leaning on the hill rock, the view being taken from the south, about 500 yards distant. Fig. 36 B represents the same boulder, viewed from the north, at a distance of about 10 yards.

Matheson next informed the Convener that if the latter wished to see the biggest boulder in Glencoe, he would have to cross to the opposite side, at a place about a mile further down, and at a considerable height above the river channel.

The Convener went to the place and found the boulder in

question. A path from the cottage occupied by Buchanan (a shepherd) led to it. The boulder being of very irregular shape, its exact dimensions were not ascertained. Its girth at the level of the ground was ascertained, by walking round it, to be 22 yards. Its height seemed to be about 15 feet. The rock composing it was a coarse conglomerate. It was resting on a flat or terrace of gravel. Its height above the channel of the river was about 450 feet, and above the sea 1215 feet.

The position of the boulder seems to be indicated on the Ordnance map by the words "Meannar Clach."

The Convener was unable to form a distinct opinion on the question, whether this boulder had come down the glen, or had come up the glen. Its height above the sea was nearly the same as the conglomerate cliff higher up the glen, before spoken of. But, if a fragment from that cliff, it must have crossed the valley. The following considerations favoured the idea that it had been floated *up* the valley. It was resting on the shoulder of a hill facing the N.W.; and on the same shoulder there were multitudes of smaller boulders of conglomerate rock, apparently due to the same mode of transport. A plan of the position is shown on fig. 37, where B represents the big boulder. Some boulders, apparently of a similar character, were visible at A, though they were not visited. If a N.W. current, bearing boulders, came up the glen, it might lodge the boulders at A and B. The Convener believes that conglomerate rock occurs near the foot of Glencoe, as, when there, he saw fragments which appeared to have fallen from a cliff. If this be the case, the theory which ascribes transport of these boulders *up* the glen would be strengthened.

It was observed, that the above "big boulder" rests on a terrace of gravel. It is rather a bed of stony clay, as such seemed to be the character of sections cut through by streams for about 200 feet above the boulder; and this stony clay contained numbers of pebbles and small boulders. It was plainly a water deposit. Above this stony clay, there appeared to be extensive beds of sand; and on several of the hills, near the foot of Glencoe, even up to the height of 2000 feet, sand in large quantities was observed; but it was only through a telescope that the observation was made.

About half a mile below Buchanan's cottage, at the ninth milestone from Ballachulish, the Convener observed a rock well smoothed

and striated; it was at the side of the highroad. The surface of the rock sloped due south at an angle of about 15°. The striæ had a direction N. 55° W.; whilst the axis of the valley here was N. 65° W. There was nothing to indicate whether the striating agent had moved up or moved down the glen.

One of the most interesting spots in Glencoe is where the valley is narrowest, *i.e.*, where the hills on each side approach so near, that their respective rocky cliffs front each other at a distance of only about 300 yards. This narrow defile occurs about a mile to the west of Buchanan's cottage. The river here has cut through the slaty schist rocks to a depth of about 60 feet.

Fig. 38 will give some idea of this defile. There is a large plateau of rocks, consisting of slaty schist, which has been evidently ground down by a heavy body or bodies passing and pressing over it from the *east*, *i.e.*, down the valley. There are elongated shallow hollows also on these rocks parallel with the axis of the valley, which hollows are near the middle, as if the pressure there had been much greater (viz., at A and B) than higher up at C. The smoothing and the hollowing seem to have commenced on the *east* side, as the edges of the strata are mostly smoothed on the edges facing the east. On the west side they are somewhat rough and jagged.

The figure represents a boulder lying on the smoothed rocks on the north side. It had not fallen from the cliffs. If it had, it would assuredly not have stuck in its present precarious position. It is a true erratic, and must have been brought up the glen at a period subsequent to the smoothing of the rocks. The surface of the rock on which it lies, slopes down towards the west.

About a quarter of a mile lower down the glen another smoothed rock occurs, which in like manner shows frictional agency over and upon it *from the eastward.* The rough parts of the rock face the west, and there form a cliff about 50 feet high, which has evidently stopped a number of erratics in their progress up the glen, as they lie in great numbers at the foot of the crag, some resting on others. Fig. 39 represent these boulders, showing how they have been obstructed, and how the uppermost boulder of the two must have come from the west to obtain its position above the other. The rocks in the cliff are a reddish felspar. The boulders are a fine-grained gneiss.

The Ordnance Surveyors having reported to the Boulder Committee a very large boulder seen by them at the foot of Glencoe, and having had the goodness to indicate its exact position on their map, the Convener made an attempt to find and examine it. On the map the boulder is indicated by the name of "Craig Bhatan," which it is believed means "*rock with trees.*" The Convener saw the boulder, at the distance of about a quarter of a mile, with bushes growing on it; but he was prevented reaching it, in consequence of being unable to ford a river between him and it. The size of the boulder was stated by the Ordnance Surveyors to be 90 feet in circumference, and about 10 feet high, and it appeared to the Convener to be of that size. It lies in a meadow adjoining the River Coe, about half a mile to the S.W. of the Glencoe Hotel. The meadow is about 200 feet above the sea, and is closely surrounded by mountains exceeding in height 2000 feet on all sides except two. One of these sides, to the east, is the valley of Glencoe. The other side, to the north, is the valley leading to the sea at Loch Leven, distant about 13 miles.

As the boulder seemed to be resting on an extensive mass of gravel, it seemed to the Convener very probable that it had come from the north, *i.e.*, up the Loch Leven Valley.

On the right bank of the River Coe, nearly opposite the large boulder just referred to, there is a rocky knoll standing from 20 to 30 feet above the adjoining district. This knoll has had lodged on its north side, a number of boulders, whose relative positions indicate transport from the north, *i.e.*, up the glen. One of these is a dark micaceous rock, glistering with abundance of mica. A few hundred yards to the north of the knoll, there is a rocky conical hill, reaching to a height of about 90 feet above the adjoining district. It is on the map called "Tom a Grianain." It consists of vertical strata of mica schist,—the only place where, in the course of this day's perambulation, that kind of rock was seen. There can be little doubt, therefore, that the mica schist boulder just mentioned had come from "Tom a Grianain," *i.e.*, from the north, and been torn from the hill by floating ice.

The facts ascertained in Glencoe seem to indicate two separate agencies. In the first place, there was a glacier, which planed down the rocks, so as to produce the extensive smoothings and groovings

seen at the narrow defile and elsewhere. In the second place, and subsequent to that epoch, the whole of the mountains in this district underwent submergence beneath the sea, in consequence of which not only was the Glencoe valley filled and choked with gravel, clay, and sand; but the highest hills adjoining were under water, and subjected to a great sea-current, loaded with ice, which flowed from the N.W. This glacial current brought from hills in the west, fragments of rocks from these hills, and dropped them in the valley at various points.

XIV.—GAIRLOCH.

In this district, the hills adjoining the coast present on their west slopes, even to their tops, numerous examples of large boulders.

1. Fig. 40 indicates the hills immediately above the Hotel, with coloured dots to represent the boulders on them.

One of these, the Convener found to be in the position and of the dimensions shown in fig. 41.

Its height above the sea is 675 feet; but the important feature is that it is on the verge of a precipice, which goes sheer down vertically about 100 feet. The boulder is a coarse-grained reddish brown sandstone, entirely different from the rocks of the hills, which consist of a slaty schist—being a variety of gneiss. The longer axis of the boulder lies N.W. by W.

There are several other boulders visible along or near to the verge of the cliffs, most of them consisting of the same sort of sandstone, and some consisting of a reddish granite—all evidently erratics.

On the lower slopes of these hills, facing the west, there are hundreds of similar boulders. They are mostly rounded at the ends, and in that respect are quite distinguishable from the rock fragments lying also on the hill slopes, which have fallen from the cliffs above.

2. To the N.E. of Gairloch Hotel there are other perched boulders. Fig. 42 shows one of them resting on a small ledge of gneiss rock, whose general slope is due west at an angle of about 50°. It rests on the rock only at its east end; the west half for about 5 feet does not touch the rock of the hill at all. Its height above the sea is 657 feet.

This boulder could have been deposited on its narrow site only by floating to it from the westward.

3. Fig. 43 represents a boulder on another hill near Gairloch, 747 feet above the sea, on the edge of a high cliff facing the west, and partially resting on two small boulders at its east end. It is a coarse-grained granite, whilst the rock of the hill is a schistose gneiss. It projects 2½ feet beyond the edge, and it in like manner could not possibly have obtained its position except by being brought from the west.

4. Fig. 44 represents a hill about one mile N.E. from Gairloch Hotel, at the top of which (585 feet above the sea) two boulders attract notice. The largest is a block of close-grained Silurian rock, blue in colour and very hard. The smaller is a small block of reddish-brown sandstone, with minute pebbles in it of quartz and felspar. The rock of the hill here is a bluish clay slate, the strata of which are almost vertical.

Fig. 45 is a representation of the largest of these boulders taken from its N.E. side at a distance of about 10 yards. The Convener, on a minute examination, found that the boulder was resting on the rock of the hill, at three points, and that at the lower end it projected 2 feet beyond one of the points of attachment. The boulder sloped down towards the N.W. at an angle of 15°. The points of attachment to the rock seemed so slight that the Convener thought he would have little difficulty with a crowbar in precipitating the boulder down the precipice.

The red sandstone boulder is about 10 yards distant from the large boulder, and lay on a rocky surface facing the W.N.W.

5. Near the foot of the hill just referred to, there is a rocky knoll on the top of which a number of true erratics are clustered. The uppermost is 6 × 5 × 3 feet in size, and lies in such a position over the others as to show that it had most probably come from the N.W. This cluster is shown on fig. 46.

6. There was only one place where striæ on a smoothed rock surface were observed. It was about half a mile to the N.E. of Gairloch Hotel, its height above the sea 340 feet. Fig. 47 represents this rock surface. It slopes about due west at an angle of 30°, till it comes to a nearly vertical cliff. The boulder is 10 feet high, 6 feet wide, and about 4 feet thick. It is within 2 or 3 feet of the edge of the precipice, which is about 50 to 60 feet high. On one side of the boulder, several striæ are visible, running E. by N. They had apparently com-

menced at or near the edge of the precipice, viz., at their west ends, as they are deeper and wider at that end than at the east end.

Betweeu Gairloch and Loch Fionn, a distance of about 10 miles, all the hills have abundance of boulders on their sides up to their tops, and generally these are most numerous on the west sides; but at one place, 600 feet above the sea, two boulders were observed on a rock surface sloping towards the W.S.W., and which apparently had come upon the hill from that quarter.

At first the Convener was surprised to find that the smooth rock surfaces, and some of the boulders in the district between Gairloch and Loch Fionn indicated agency not from the N.W. but from the W.S.W. He ultimately saw an explanation of this deviation from the normal direction, by the existence of a high range of hills due east of Gairloch, which might have deflected a N.W. current, and caused it to flow E.N.E. instead of S.E.

It has been mentioned that most of the boulders on the hills near Gairloch are composed of a reddish brown sandstone rock with small pebbles in it, and that this rock is entirely different from the rocks of these hills.

This reddish-brown sandstone rock exists largely *in situ* along the the coast to the N.W. of Gairloch. Professor Geikie, in his recent Geological Map of Scotland, states this to be the case. It is also spoken to, as existing in that quarter, by Professor Nicol and by Robert Chambers. There can be no doubt, therefore, that these Gairloch sandstone boulders, as seen by the Convener at levels exceeding 700 feet above the sea, have come from that district—as indeed the boulders themselves indicate alike by their situation and their altitudes on the hills.

XV.—LOCH MAREE.

The road from Gairloch to Loch Maree passes through a valley running for a mile or more in a direction pretty uniformly W.N.W. and E.S.E. At several places on the roadside smoothed rocks were observed with striæ running in that direction. There was nothing to show whether the rock had been smoothed and striated by a glacier or by sea ice.

On the hills to the west of Loch Maree Hotel, reaching to a height of about 1000 feet above the sea, multitudes of red sandstone

boulders occur, more particularly on the N.W. sides of the hills and on their tops. On one hill (950 feet above the sea), presenting on its top a nearly level surface of about 80 yards diameter, the Convener counted twenty boulders, each exceeding 2 or 3 feet in diameter. Most of these were a coarse pebbly sandstone, the same in its general character as the Gairloch boulders; whilst there were amongst them, just as on the Gairloch hills, a few of a reddish-coloured granite. These boulders, when on or near hill tops, were

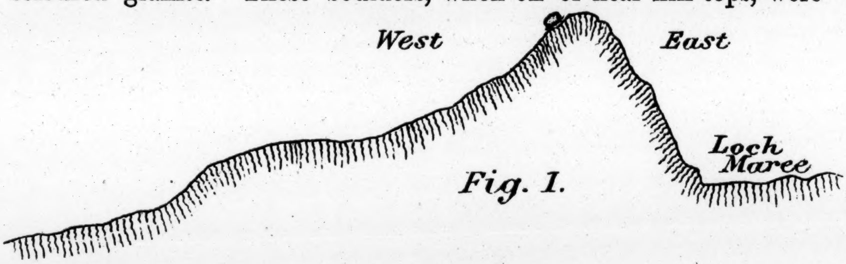


Fig. 1.

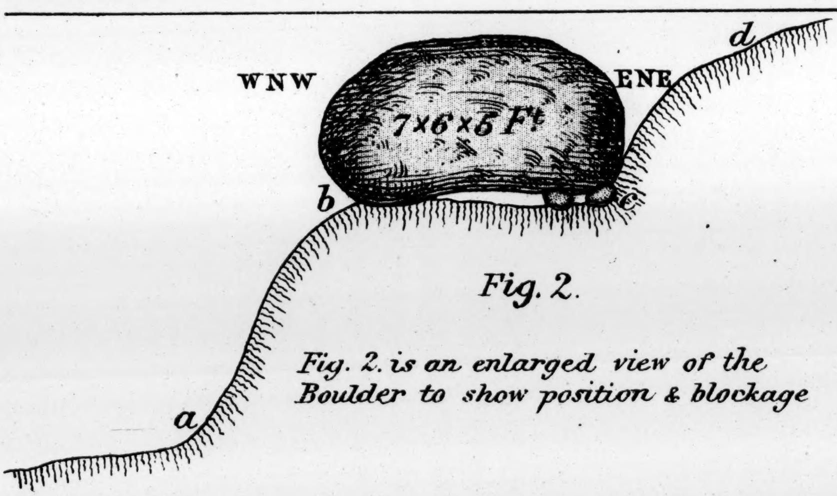


Fig. 2.

Fig. 2. is an enlarged view of the Boulder to show position & blockage

a b c d is a section of the part of the hill on which the boulder rests; *a b* is a clift about 30 feet, nearly vertical; *b c* is a shelf on which the boulder rests; *c d* is a steep ledge of rock against which the boulder abuts at its east end. It there rests partly on rock, partly on small boulders.

lying on the bare *well-rounded gneiss rock*, and when on the sides of hills, were generally *on* or *in* beds of coarse gravel. One of the boulders, 4 × 3 × 3 feet, lying near a hill top on the N.W. side, had its longer axis pointing also N.W. On another gneiss hill (also west of the Hotel), and at about 310 feet above the sea, a sandstone boulder was found perched near the top, at its west side, as shown in the above section (figs. 1 and 2).

Professor Nicol, in his paper on the "Rocks of the North-West of Scotland,"* with reference to the hills about Loch Maree and Gairloch, adverts to their being "still strewed with innumerable fragments of red sandstone, perched, like sentinels, in the most exposed and perilous positions, on the very edge of some lofty cliff, or on the polished summit of the domes of gneiss." In a footnote he remarks it as "a curious fact that, on these gneiss hills, by far the majority, probably nine-tenths or more, of these 'perched blocks,' are red sandstone."

The fact would be "curious," if these sandstone boulders had been, as Professor Nicol supposed, "floated on icebergs from the mountains from the east" (page 39), because, to the east of Gairloch and Loch Maree there are no mountains of red sandstone. Professor Nicol, in this paper particularly adverts to "the red sandstone as forming a narrow band along the western shore, never reaching to the watershed of the country." Again (page 37), he repeats, that "the red sandstone on the west forms a narrow band along the shore, and never extended far into the interior."

That being the case, it would indeed be "curious" if the red sandstone boulders which cover the hills about Gairloch and Loch Maree had all been "floated on icebergs from the east." But assume that they had been floated from the N.W., and an explanation is at once obtained.

A curious belt of sandstone rocks occurs to the south of Loch Maree Hotel. Through and across this belt the high road passes for about two miles, so that an excellent view is obtained of the remarkable dislocations and denudations of these rocks which have occurred. These rocks differ in many respects from the rock of the sandstone boulders to which reference has just been made.

Professor Nicol explains that the sandstone of the west coast is "a coarse *grit*, graduating into a *fine conglomerate*, with fragments rarely an inch or more in diameter" (page 19). That is the character of the rock, forming the boulders; but the sandstone rocks which occur near the south end of Loch Maree are correctly described by Professor Nicol as "a very remarkable *breccia* of quartz and gneiss in sharp, angular fragments," the largest of which fragments noticed by him he measured, and found it to be "16

* Proceedings of the London Geological Society, for 1856, p. 29.

inches long by 9 broad and 7 thick, but the generality are much smaller" (page 28).

Referring to this peculiar rock, Professor Nicol observes:— "The red sandstone in this district has undergone enormous denudation. On the shore of Loch Maree it is often broken up into huge masses or divided by gaps and fissures, some of them 20 to 30 feet deep. The surface of the beds is strewed with immense angular and ruin-like blocks, some of them poised on a single corner on the very edge of a cliff. All this indicates extensive destruction of the strata. Detached fragments of the breccia are found in hollows of the gneiss hills, far from the main masses evidently left there in the general denudation."

Now in what direction were these "fragments carried," and from what quarter did this "general denudation"—this "enormous denudation"—come?

The following facts leave no doubt on the subject:—The smoothed surfaces of these breccia rocks face N.W.; the rough sides are towards the S.E. Fragments lie on the surface to the south, beyond the line which separates these rocks as a formation from the quartzite rocks of Ben Eay. Within the limits of the formation, huge masses, weighing hundreds of tons, are lying at the north base of cliffs—not having fallen from these cliffs, but apparently brought there from the north, and left there, in consequence of baving been obstructed and arrested by the cliffs in their further progress to the south.

These facts are in entire consistency with the theory of a strong ice-laden sea current which flowed from the N.W. The valley now occupied by Loch Maree, with mountains on each side exceeding 1000 feet in height, happens to run N.W. and S.E., so that when this district was submerged, a glacial current flowing from a northerly point would produce all the effects on these breccia rocks which have been described.

Before passing from the district of Gairloch and Loch Maree, the Convener thinks it only due to his friend the late Robert Chambers to advert to the observations which he made in districts adjoining to the north. He makes this reference, as the facts observed by Chambers have a close relation to those which the Convener has just been describing.

Dr Chambers' paper was read before this Society in December 1852, and was published in the "Edin. New Phil. Journal" for 1853. The author's chief object was to point out that there were, in his opinion, two sets of phenomena in regard to boulders and smoothed rocks. One set he considered to be the effects of local glaciers, the other he ascribed to a general glaciation of the entire country.

The Convener does not mean to discuss this theory. He wishes only to notice the facts which Dr Chambers brought forward in support of it.

Dr Chambers states—

1. That on Cuineag and Canish (quartz hills in Assynt, situated about thirty miles to the north of Gairloch), he found, "up to a height of 1700 and 1800 feet, striæ running from about N. 60° W., with certain exceptions. One of these exceptions was at the base of Cuineag, where the streaks are from the direct north, apparently by reason of the turn which the agent had there received from the base of the adjoining hill. Another exception was at the hollow dividing the mass of the hill from its loftiest top, where another system of streakings had come in from the direct west."

2. "On a summit south from Ben More, fully 1500 feet high, and four or five miles to the S.E. of Cuineag, there are streakings on the quartz, observing the normal direction of this general movement, viz., from N. 60° W."

3. On the gneissic platform between Coul More and Suilvean (south part of Assynt), Dr Chambers says he "found polished surfaces striated from N.W. to W. To the west and north of the latter mountain are markings in all respects similar. These are situations where no local glaciers could exist."

4. "Streaking, precisely the same as that of Cuineag and Canish, exists at an elevation of at least 2000 feet on the similar quartz mountain named Ben Eay, south of Loch Maree, and forty miles from Assynt—this striation being from N.W. or thereabouts, and totally irrespective of the form of the hill."

5. "Passing northward to Rhiconich, we find near that place striæ coming in from the coast, viz., from the N.W., and passing across a high moor, with no regard whatever to the inequalities of the ground."

6. "A little further north, at Laxford, a fine surface is marked with striation from the N.W., being across the valley in which it occurs. At an opening in the bold gneissic coast which looks out upon the Pentland Firth, there is strong marking in a direction from N.N.W."

7. "The high desolate tract called Moin, between Loch Eribol and Tongue bay, where there is nothing that could restrain or guide the movement of the ice, exhibits striation from N. 28° W.

8. "Striæ, N. 25° W., occur four miles to the east of Tongue bay."

Thus at all these localities north of Gairloch visited by Chambers, the rock striations were such as to satisfy him that some vast agent from the N.W.—*i.e.*, from the Atlantic Ocean—had struck upon the country, and left its marks on hills up to a height of at least 2000 feet above the present sea-level.

XVI.—STRATHGLASS AND GLEN URQUHART.

The Convener, in September last, proceeded up Strathglass, with the view of ascending the mountain called "Mam Saul," about 3880 feet high, in quest of what was supposed by the Ordnance Surveyors to be an old sea terrace. Weather both stormy and hazy defeated this attempt; but whilst in the district, the Convener, accompanied by Mr Jolly of Inverness, made some observations perhaps not undeserving of being recorded.

On the hill above Affric Hotel, on the east side of the River Cannich, a rock was met with, planed and striated, at a height of 450 feet above the bridge across that river, and about 720 feet above the sea. The striæ were running north by west, a direction coinciding with that of Cannich valley.

At a height of 970 feet above the sea a granite boulder was lying on the upturned edges of the gneiss rock of the hill, lying in such a position as to indicate that it had probably come from a west by north direction.

At the summit of the hill, about 1170 feet above the sea, numerous boulders were found, chiefly on slopes facing the N.W.

On the high road to Drumnadrochit and Urquhart, at two or three places a few miles from Affric Hotel, rocks ground down and striated on the south side of the road were noticed. The striæ were running about east and west, or parallel with the axis of the valley.

At the top of the hill, about 660 feet above the sea, several boulders were found, the largest being 4 × 3 × 3 feet. These boulders were resting on a bed of sandy clay, and on a slope of the hill facing west by south. The west side of the boulders was well rounded, as if ground down and smoothed by the friction of bodies passing over it from the west.

All the rocks exposed on the hills here, up to the summit level of the road, which reached about 927 feet above the sea, showed smoothings on their west sides.

The whole of Glen Urquhart has evidently, at some former period, been choked with drift. Beds of gravel, clay, and sand still remain on the hills on each side up to the very top. Hence, probably, the luxuriance of vegetation which this beautiful glen manifests.

On the north bank of Loch Ness, about half a mile to the east of Urquhart, a number of conglomerate boulders lie on the hill side. In walking up the hill the Convener counted six, of which the largest was 7 × 5 × 4 feet, from a level of 200 feet to a level of 800 feet above Loch Ness.

The rocks of the hill here are gneiss, so that these boulders have been brought to where they now lie, most probably from Mealfourvounie, which consists entirely of conglomerate rock, and is situated a few miles to the west.

One of the boulders is at a height of 340 feet above Loch Ness, which corresponds with the line of an old horizontal terrace, visible along the south bank of Loch Ness to the eastward.

At the height of 450 feet above the loch, deep beds of a fine sandy clay occur, just above the landing pier at Urquhart.

XVII.—FORT AUGUSTUS.

On the Corryarrick road (about two miles S.W. of the town) one boulder was noticed which seemed to indicate the direction in which it had come. Fig. 46 shows this boulder of grey gneiss lying on a steep bank of gravel at the base of a rocky cliff, which is a buff-coloured felspathic rock. The slope of the hill is towards N.W. The boulder, therefore, probably came from that direction. It happens to be at the same height above Loch Ness (viz., 207 feet) as the lowest of the conglomerate boulders above mentioned seen to the east of Urquhart.

XVIII.—BEN NEVIS.

The track commonly followed by tourists ascending the mountain leads up the N.W. shoulder of the hill. Boulders of enormous size occur on each side of the track. The following measurements will give some idea of the size of these masses; they happened to be within from 20 to 30 yards of the track; but larger boulders were seen at a greater distance: A boulder $16 \times 10 \times 10$ feet, partially sunk in a gravel bed; a boulder $15 \times 7 \times 5$ feet, lying on rock; a boulder $13 \times 7 \times 4$ feet; a boulder nearly cubical, the sides being about 4 feet square. The three first mentioned had their longer axis N.W. and S.E.; and this was the rule with almost all the boulders, whose length was much greater than their breadth. The boulders measured were at levels above the sea between 900 and 1200 feet. But there were boulders of great size up to 2000 feet or more, and there were some near the base of the mountain. Many of these last-named had, however, been utilised for building purposes. Mr Doig, builder in Fort-William, who accompanied the Convener in his ascent, mentioned, that having been contractor for the Town Hospital, he had made use of one boulder, situated at the foot of the hill, which was four times as large as any of those above mentioned, and that all the rubble-work of the front wall of the hospital—extending to about 80 yards—had been obtained out of this boulder.

Mr Doig, who evidently was intimately acquainted with both boulders and rocks on Ben Nevis, had no doubt that all the boulders on the N.W. shoulder of the Ben were different from any rock in the mountain. He stated that the boulders were mostly all granite, both red and grey granite, but mostly grey. Those examined by the Convener were all grey granite, very similar to the rock worked at Ballachulish and Duror, about 30 miles to the west.

XIX.—SKYE.

The Convener regrets not having had an opportunity of visiting Skye, except at one spot on the west coast, viz., Loch Scavaig, where the steamer stops for an hour to allow tourists to visit Coruisk. Dr Macculloch's book, published in 1818, and the paper which the late Principal Forbes read in this Society on the Cuchullin hills (" Edin.

New Phil. Journal" for 1846) show that in different parts of the island there are boulders and smoothed rocks well deserving of careful study.

After what Principal Forbes said about the existence of smoothed rocks, and of grooves or striæ on these rocks (which he unhesitatingly ascribed to glacier action), it is impossible to dispute that on this island, small as it is, there must have been ice enough in the different corries to form glaciers. Perhaps there would be less difficulty in adopting the theory, were it supposed that Skye had stood much higher out of the sea at the time when these effects were produced.

Principal Forbes in his paper, among other effects ascribed by him to the Skye glaciers, speaks of "the occurrence of large angular detached masses of hypersthene *rock poised upon others*, or *fantastically balanced on the insulated tops of the elliptical domes of rock*" (page 92). He also, on this point, quotes Dr Macculloch, who supposed that these detached masses were merely fragments which had fallen from adjoining hills. But he admits that "the mode in which these fragments lie is remarkable. The bottom of the valley is covered with rocky eminences, of which the summits are not only bare, but often very narrow, while their declivities are steep and sometimes perpendicular. Upon these rocks the fragments lie, and in positions so extraordinary, that it is scarcely possible to conceive how they have risen so high after the rebound, or how they have remained balanced on the very verge of a precipice. One weighing about 10 tons has become a rocking stone. Another of not less than 50 tons stands on the narrow edge of a rock 100 feet higher than the ground below, which must first have met it in the descent" ("Western Islands," vol. i. p. 388).

One of these boulders, perched "on the narrow edge of a rock," was noticed by the Convener near where the boat takes passengers ashore at the head of Loch Scavaig. Fig. 48 represents this boulder—*a* shows its position relative to Lake Coruisk and the sea; *b* shows its position more exactly on the rock where it stands.

Dr Macculloch's idea of the boulder having fallen from an adjoining cliff, and *rebounded* on to the top of the rock where it stands, of course cannot be entertained.

On the other hand, if the boulder was brought by a glacier from

Fig.1.

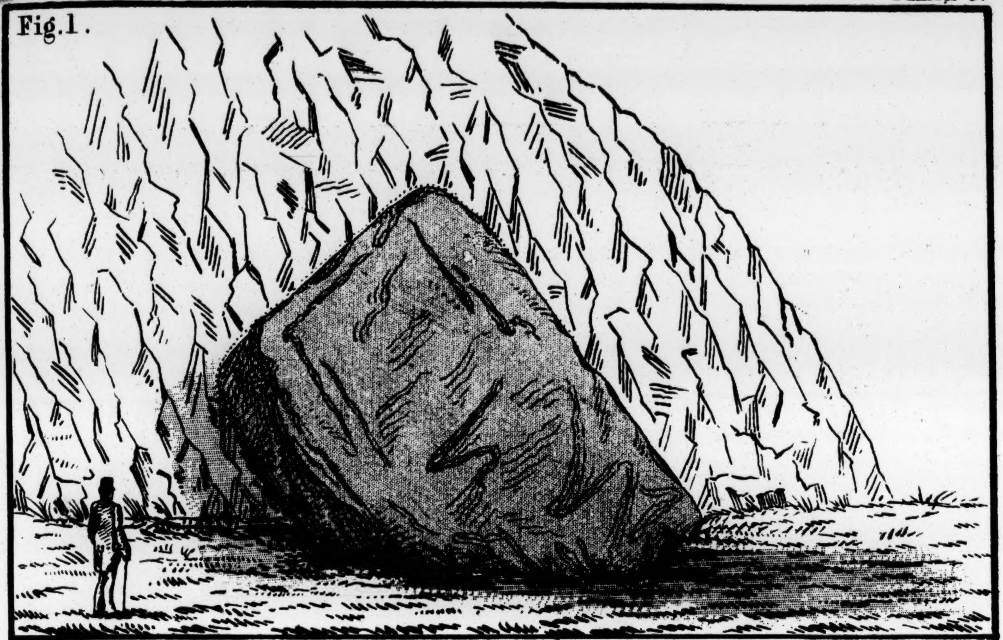


Fig.2.

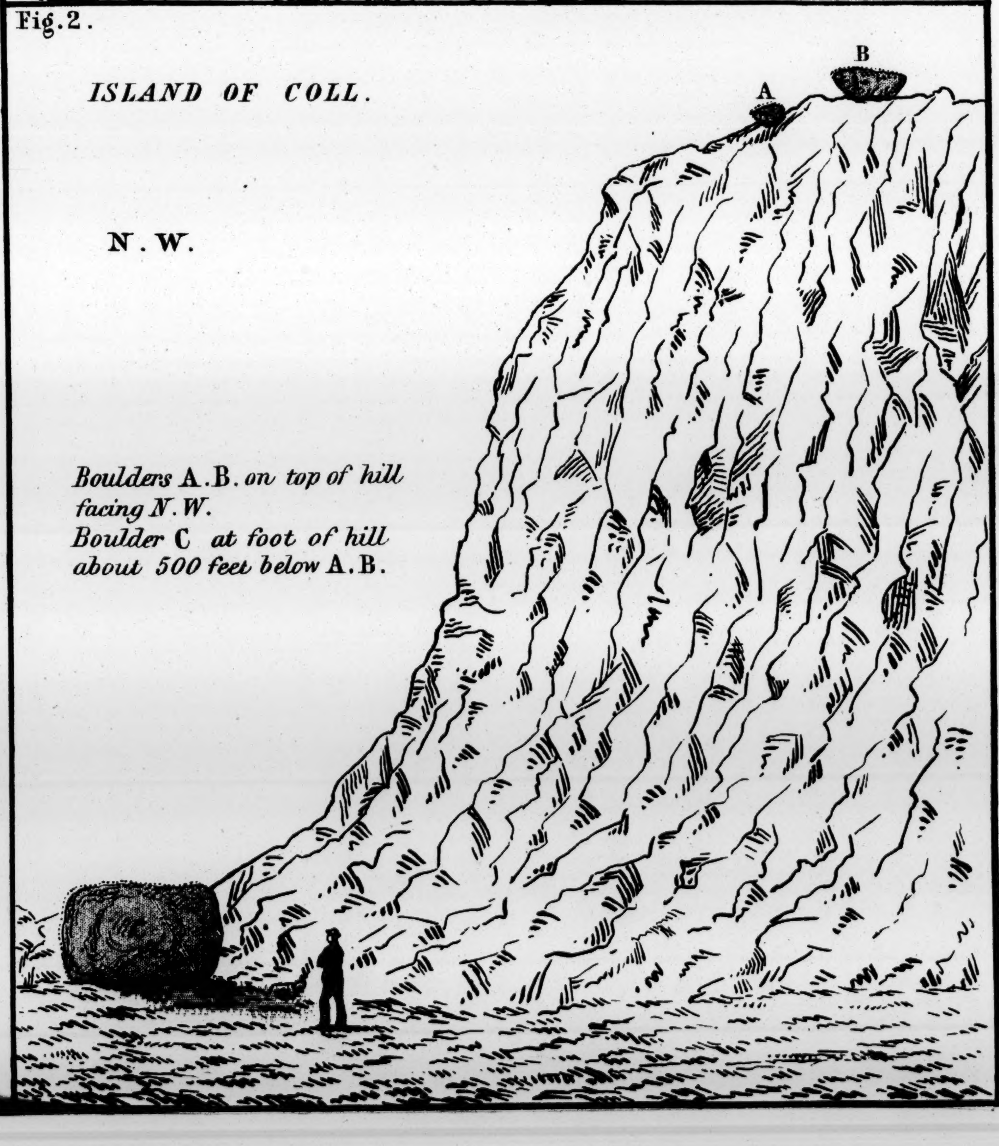

ISLAND OF COLL.
N.W.
B
A
Boulders A.B. on top of hill facing N.W.
Boulder C at foot of hill about 500 feet below A.B.

PLATE II.

Fig. 3.

Fig. 4.

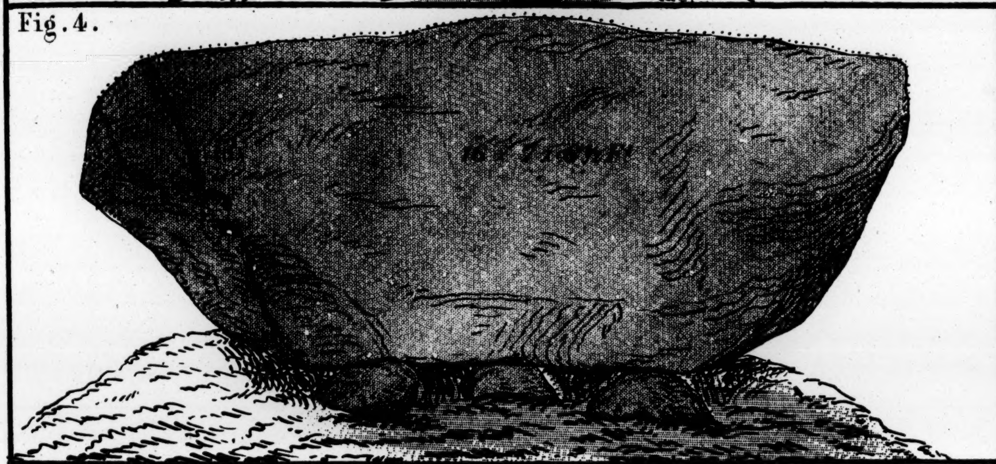


Fig. 5.

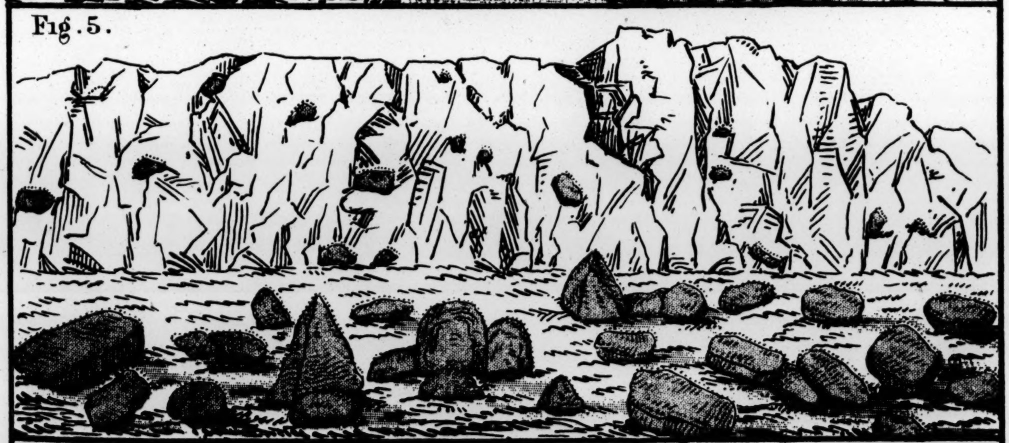


Fig. 6.

Fig. 7.

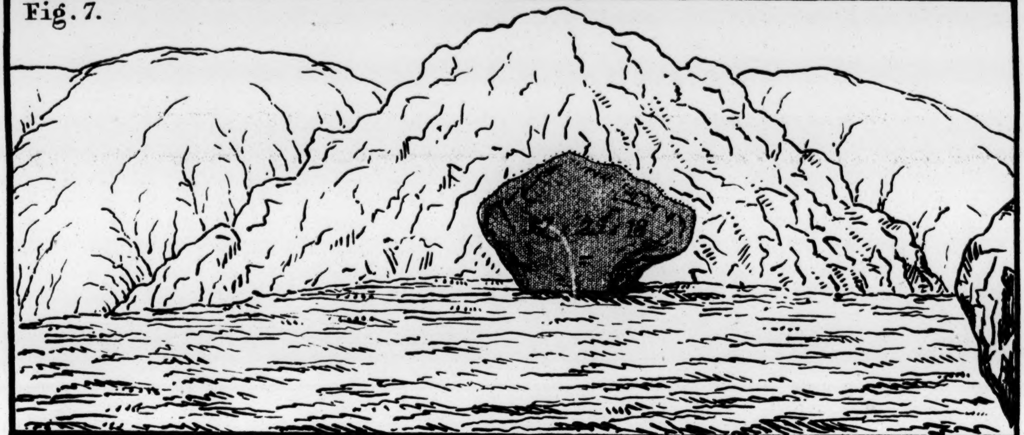


Fig. 8.

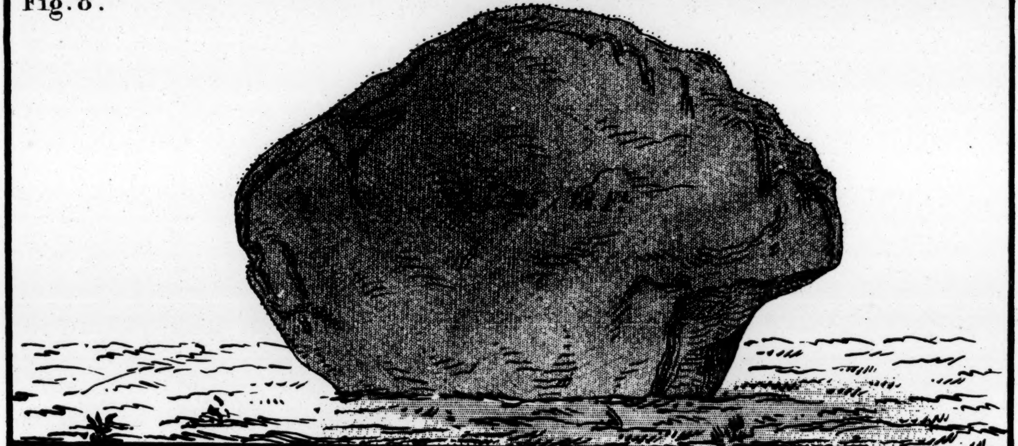


Fig. 9.

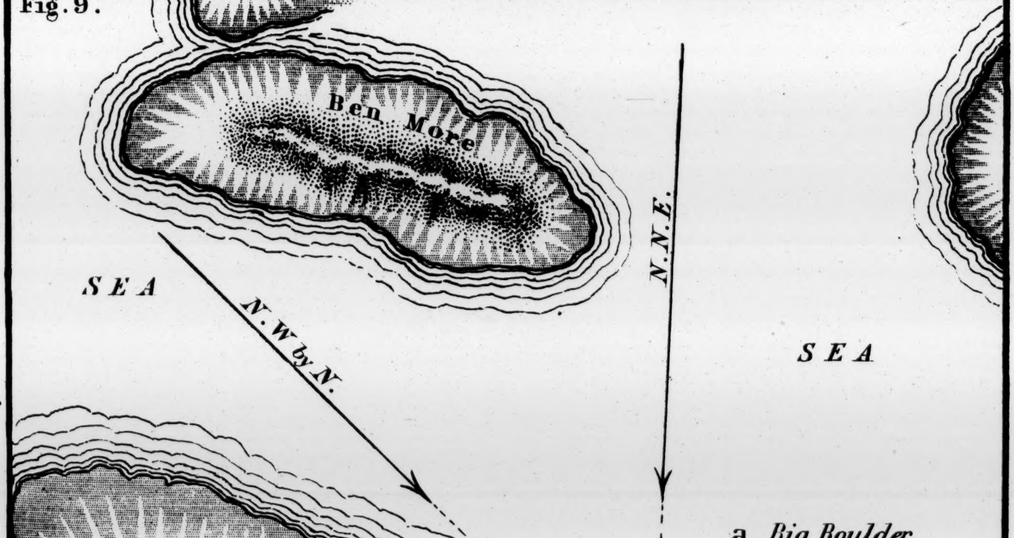


Fig. 10.

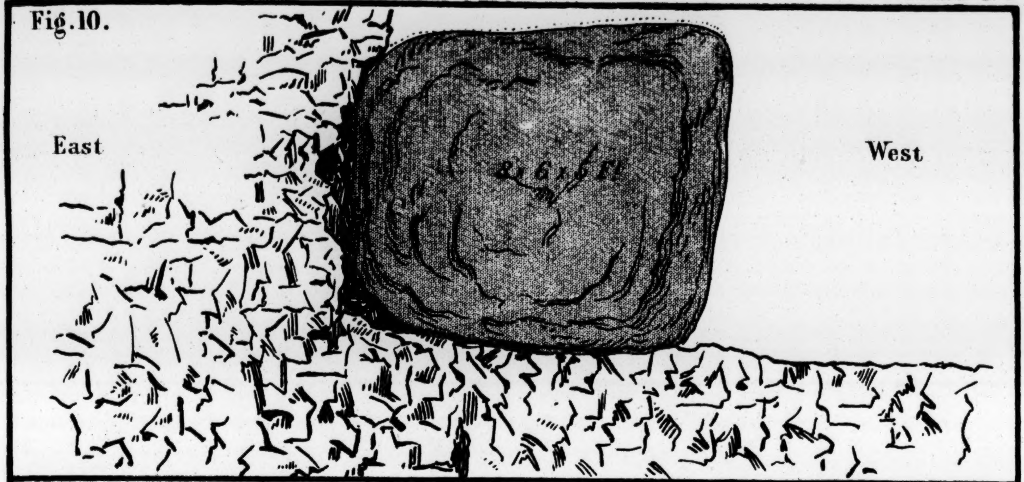


Fig. 11.

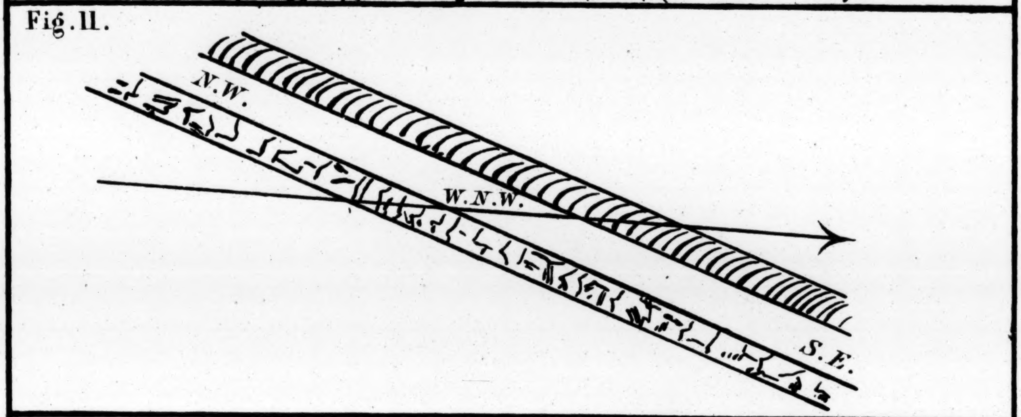


Fig. 12.

Fig. 13.

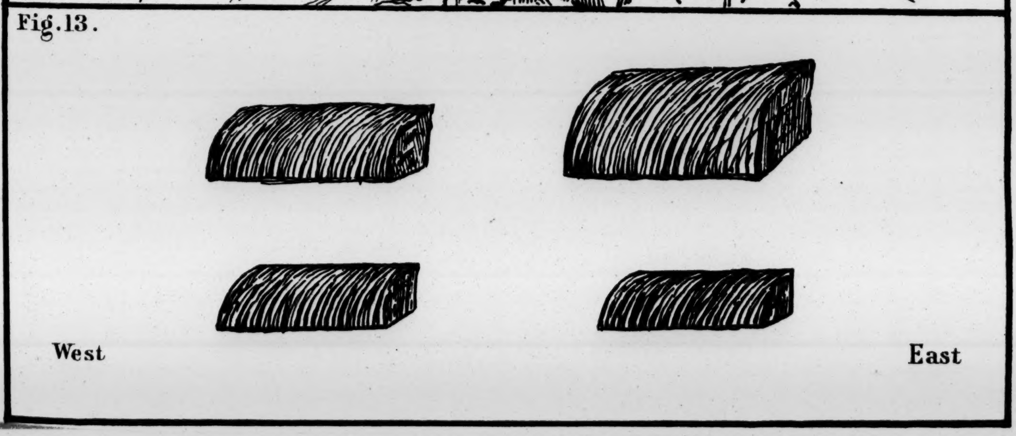


Fig. 14.

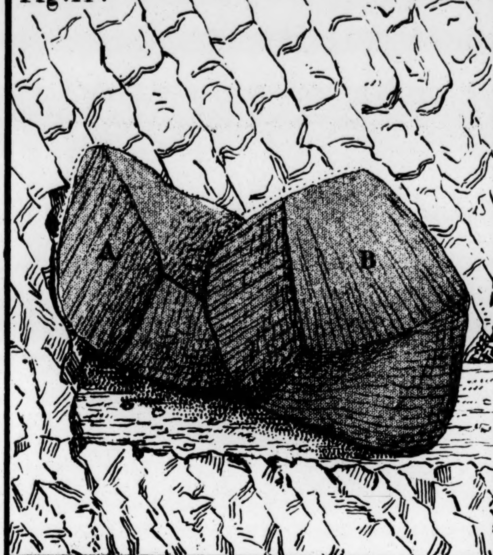


Fig. 15.

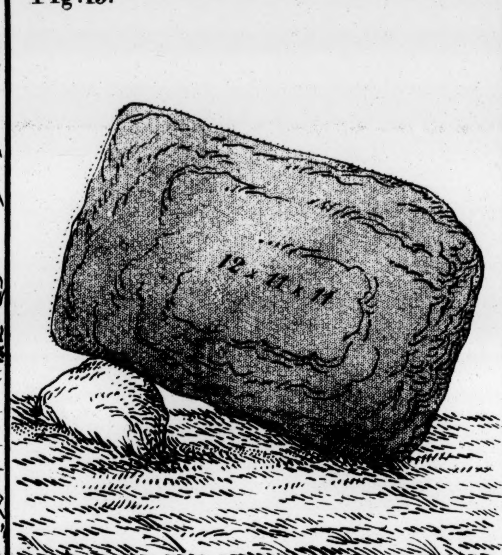


Fig. 16.

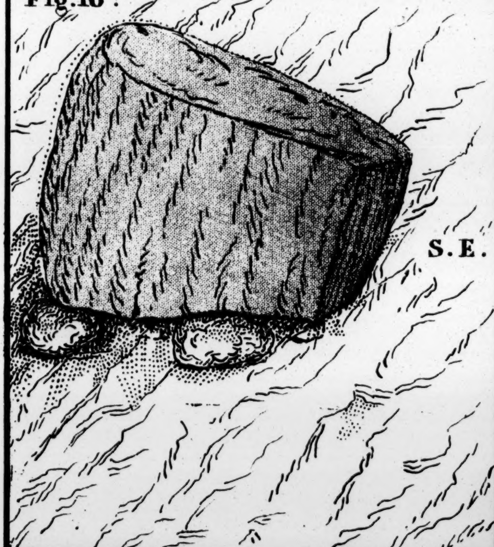


Fig. 17.

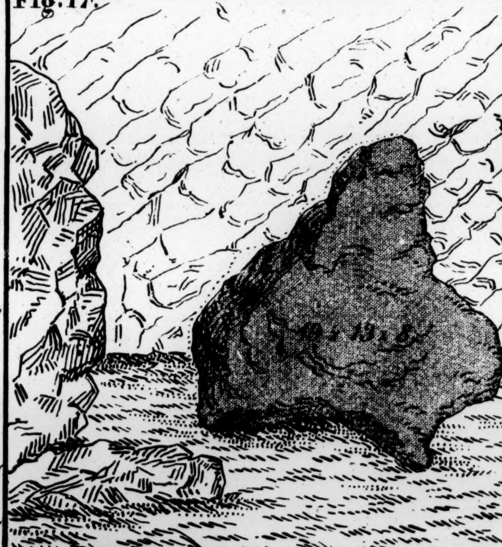


Fig. 18.

Fig. 19.

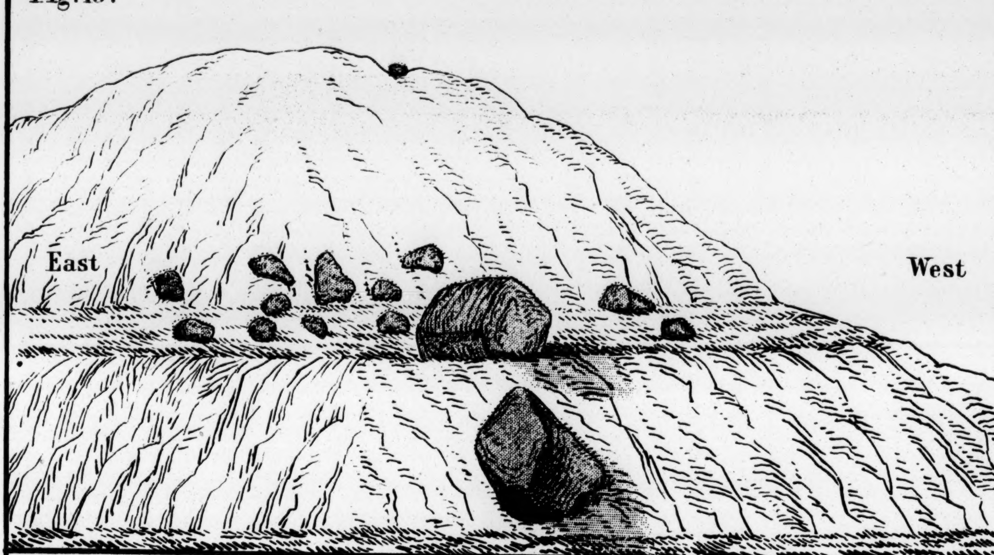


Fig. 20.

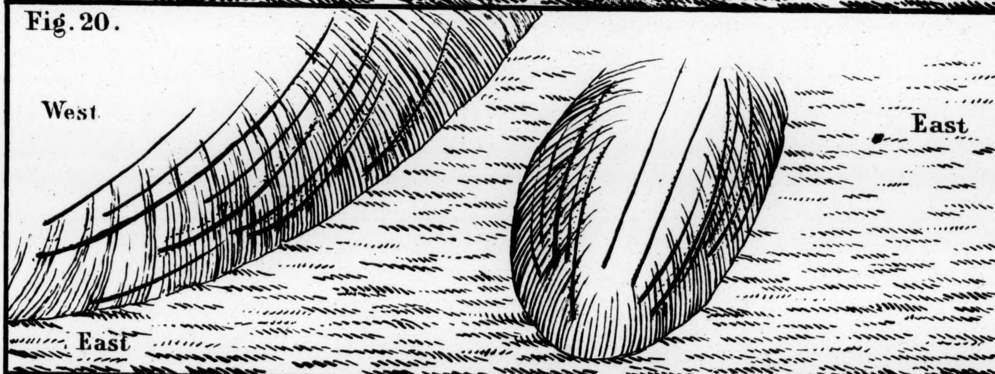


Fig. 21.

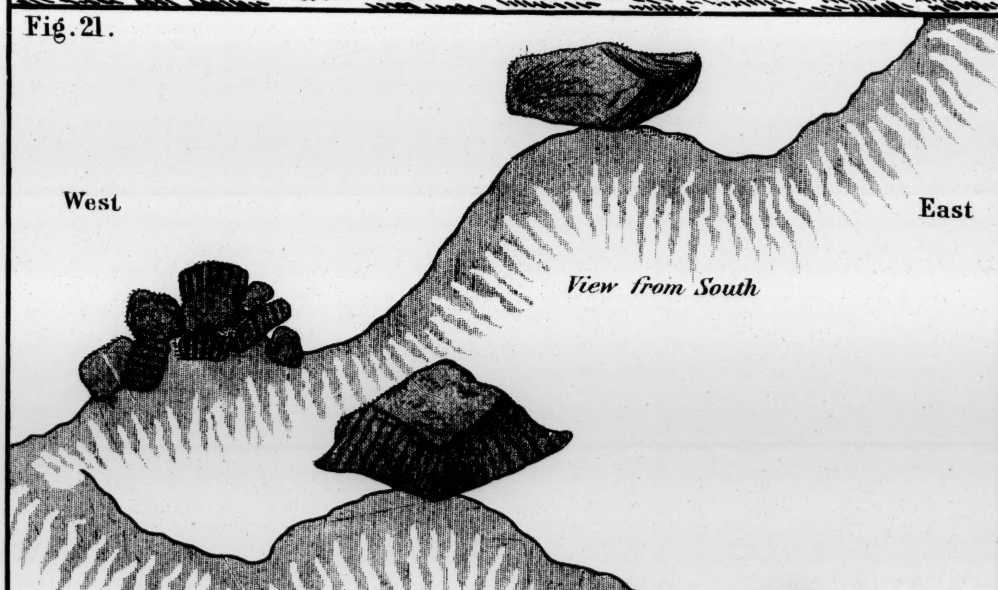


Fig. 22.

Fig. 23.

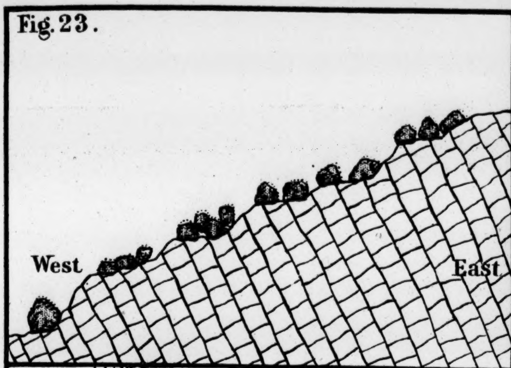


Fig. 24.

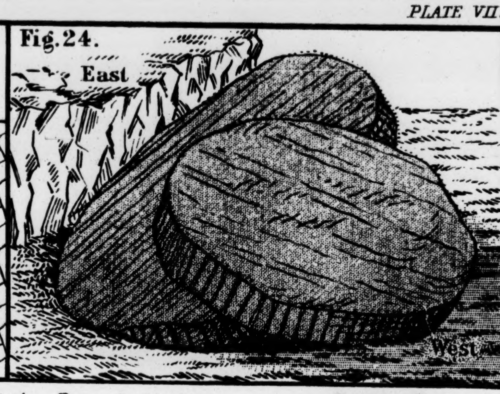


Fig. 25.

Plan of Loch-castle Bay & Valley.

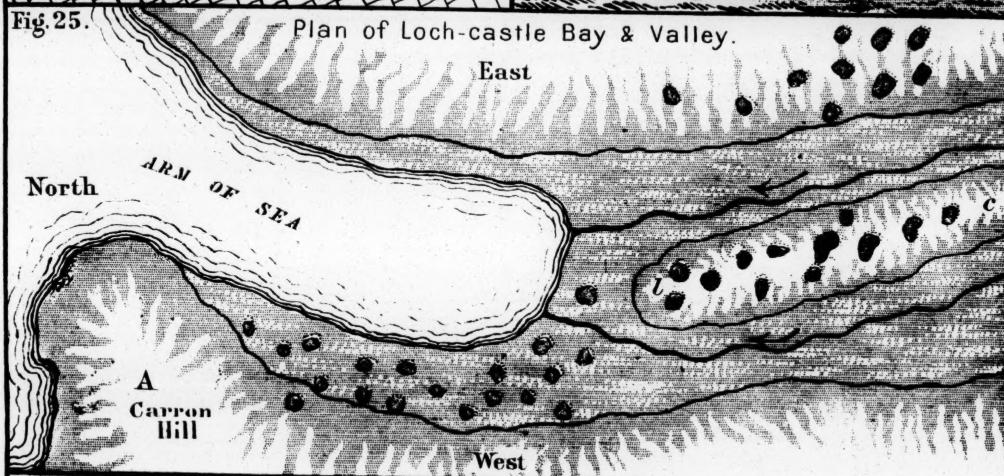


Fig. 26

Section of Loch-castle Valley.

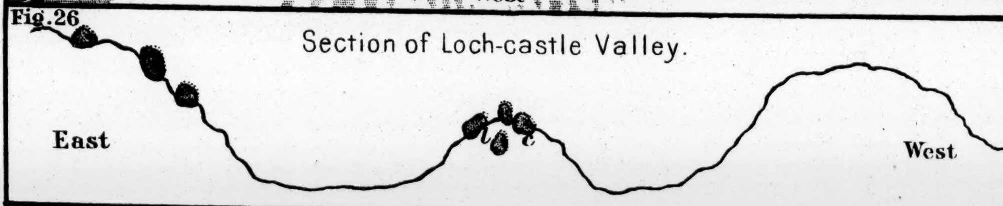


Fig. 27.

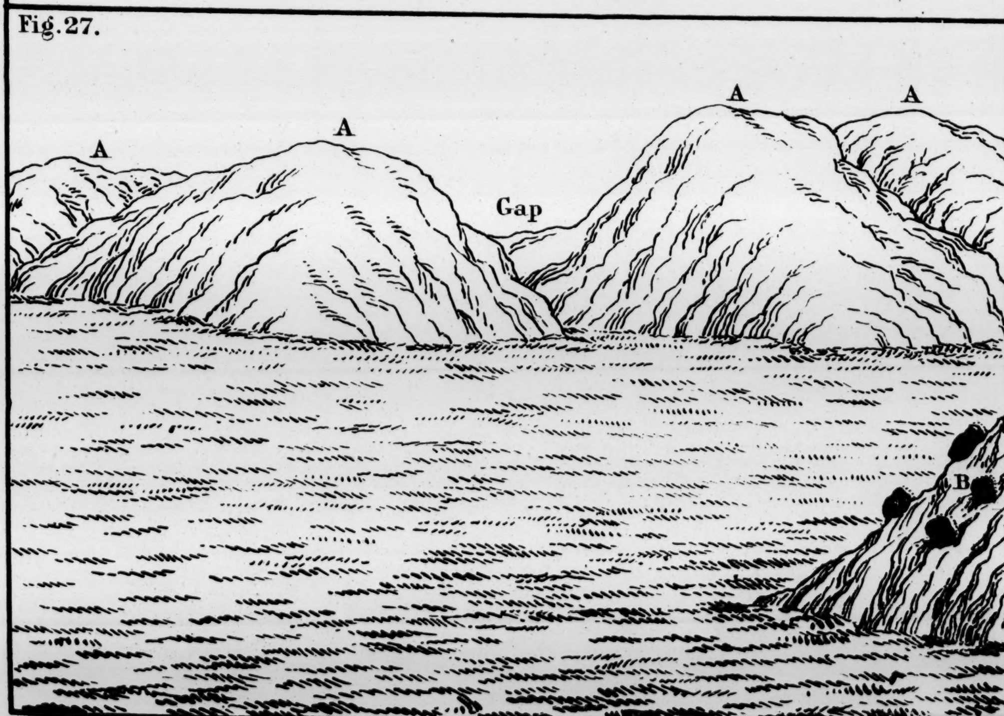


Fig. 28.

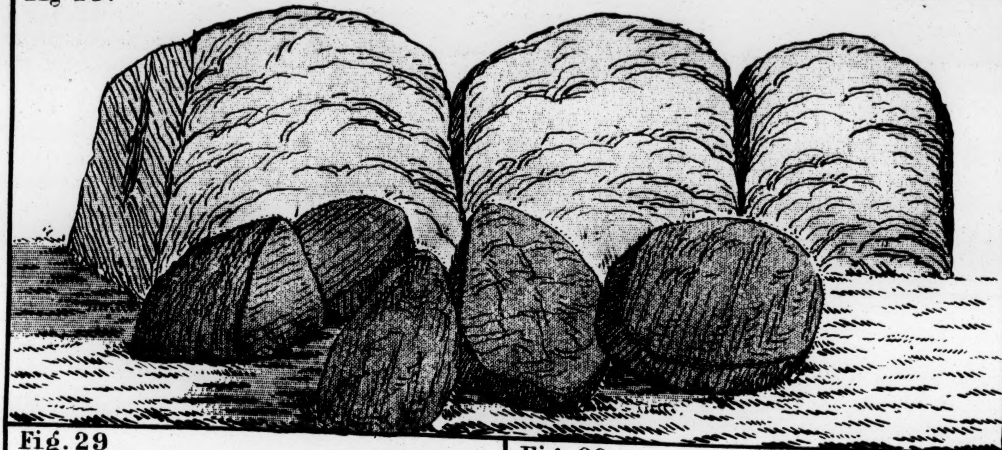


Fig. 29

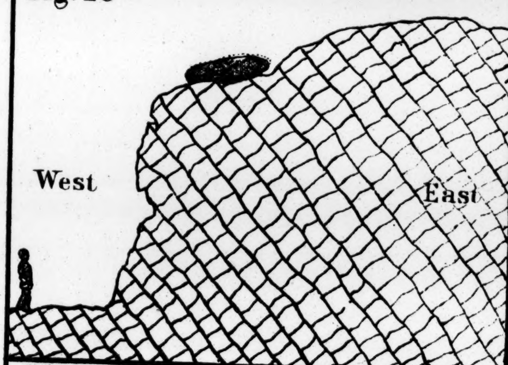


Fig. 30.

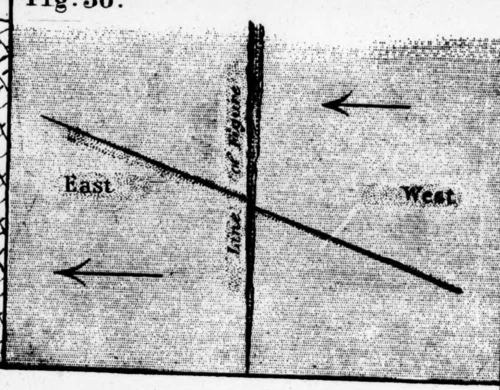


Fig. 31.

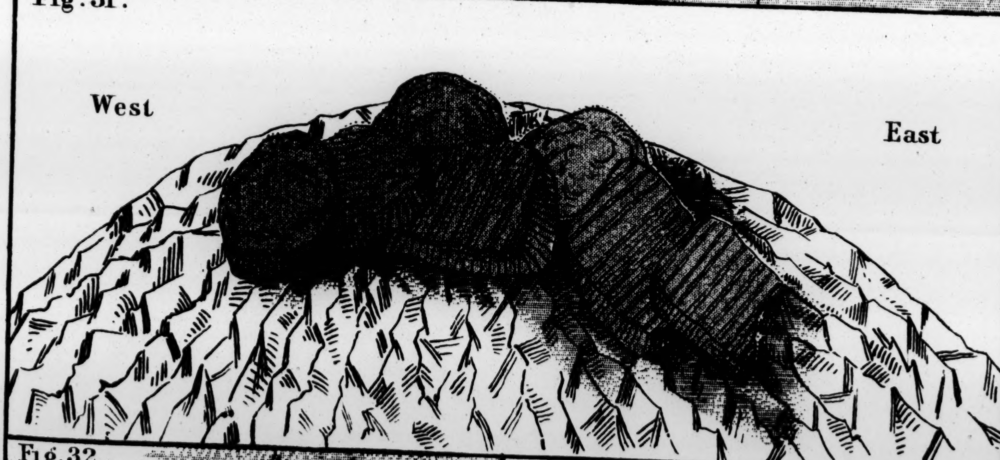
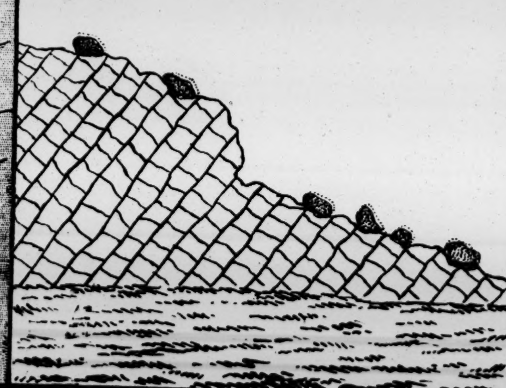
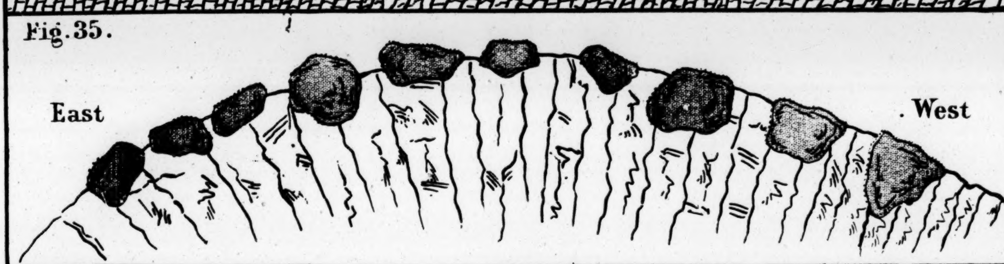
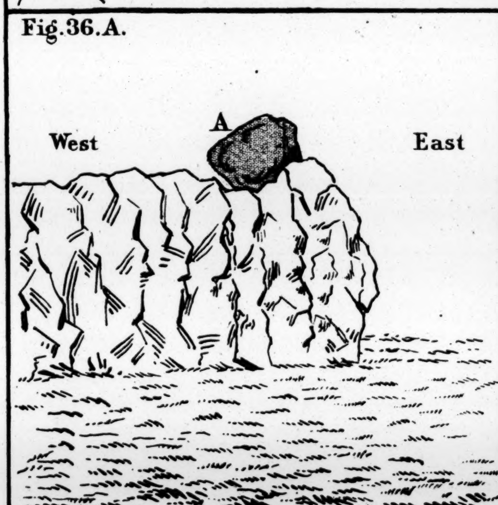


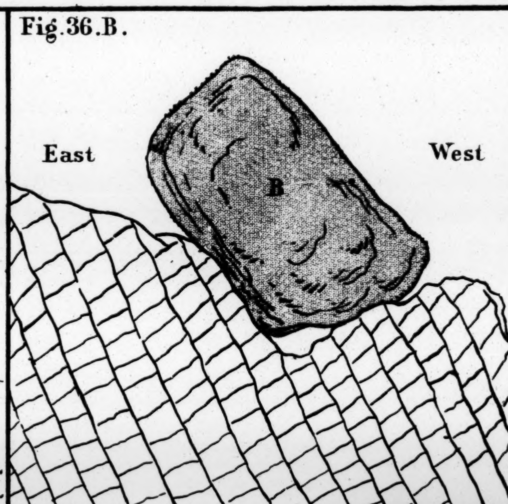
Fig. 32.

Fig. 33.









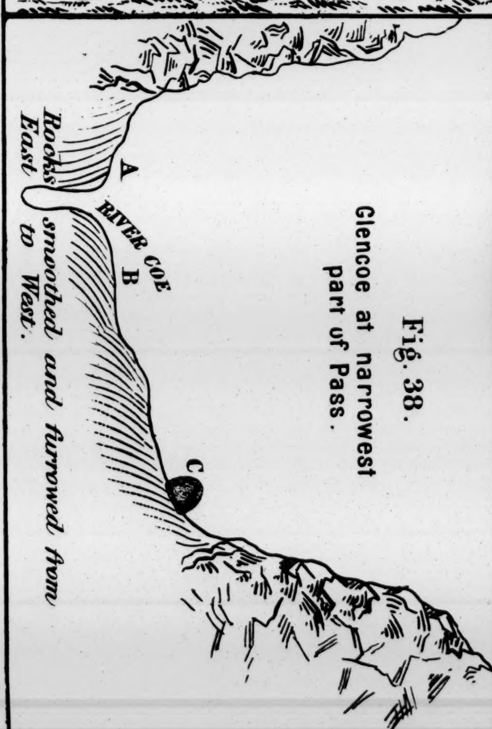


Fig. 38.
Glencoe at narrowest part of Pass.

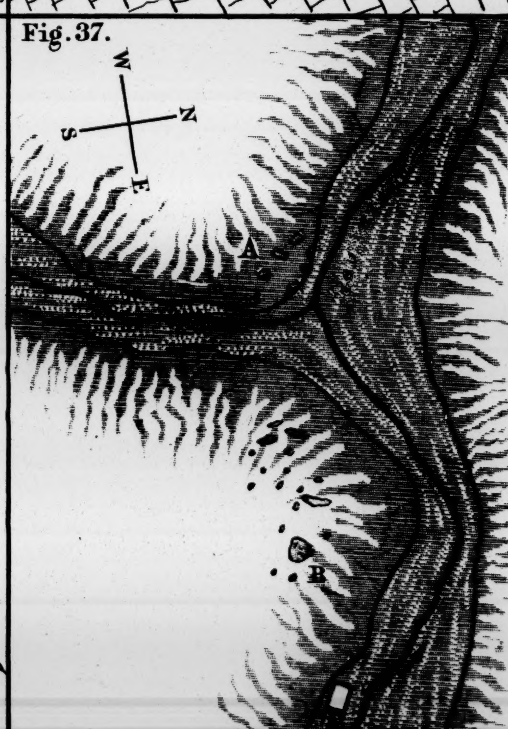


Fig 39.

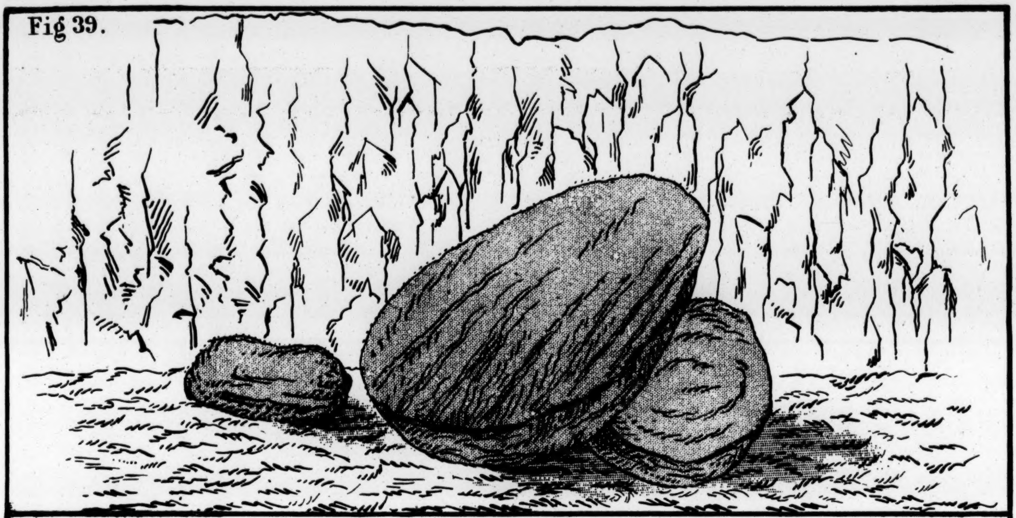


Fig. 40.

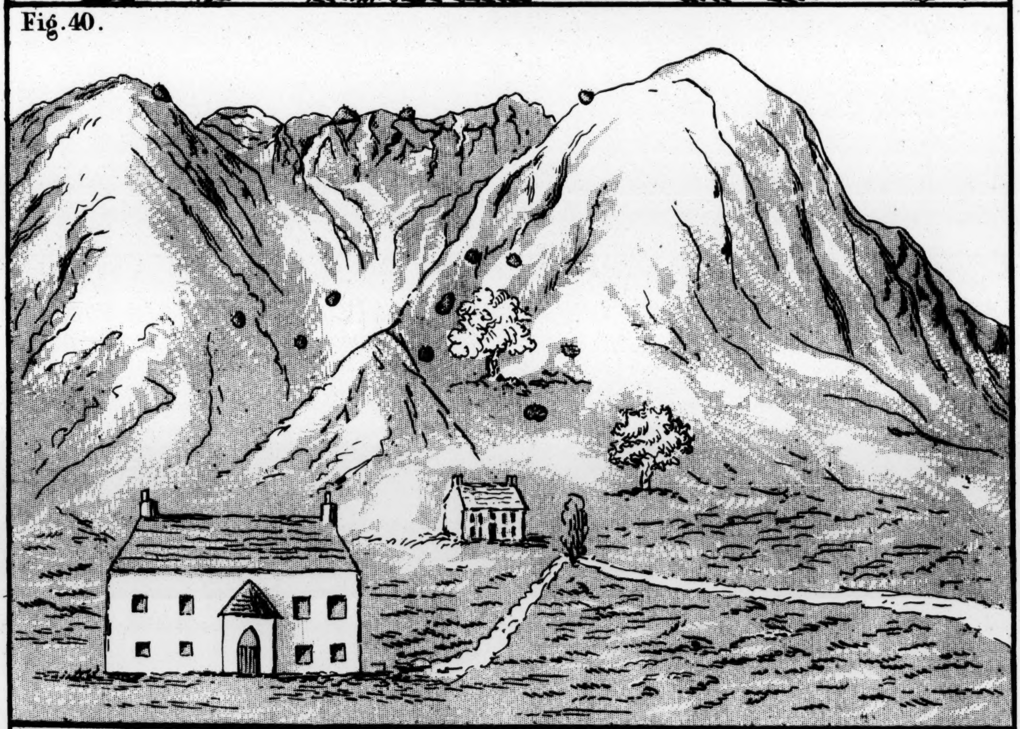


Fig. 41.

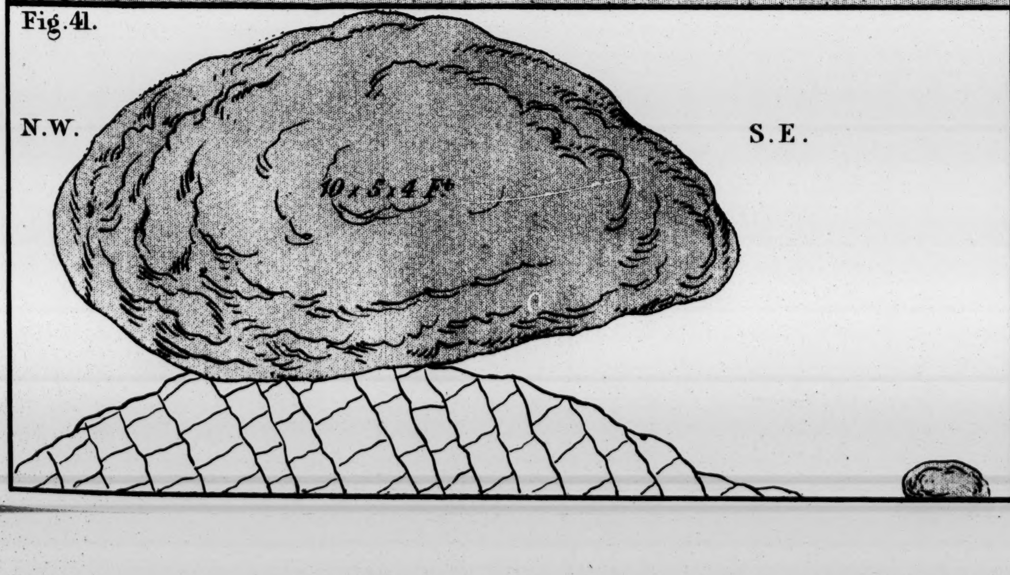


Fig. 42.

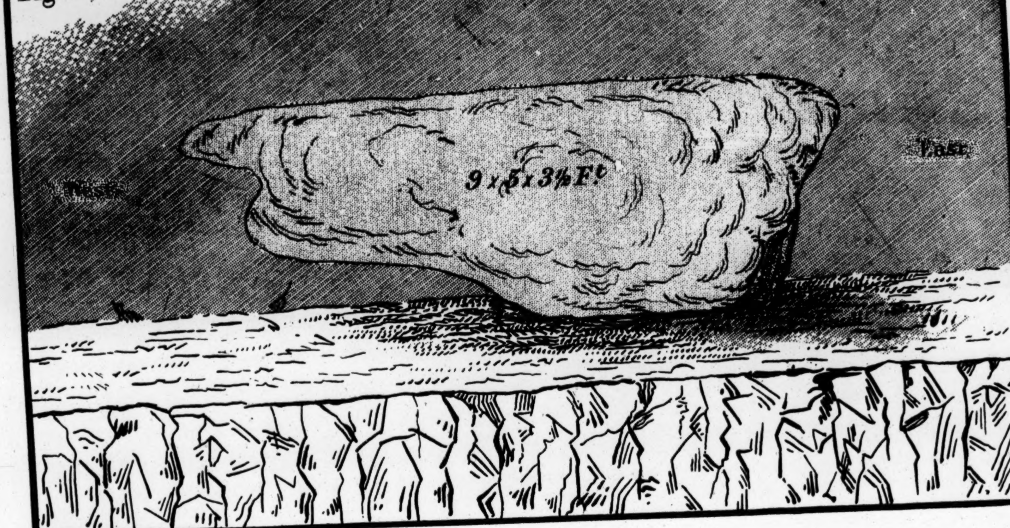


Fig. 43.

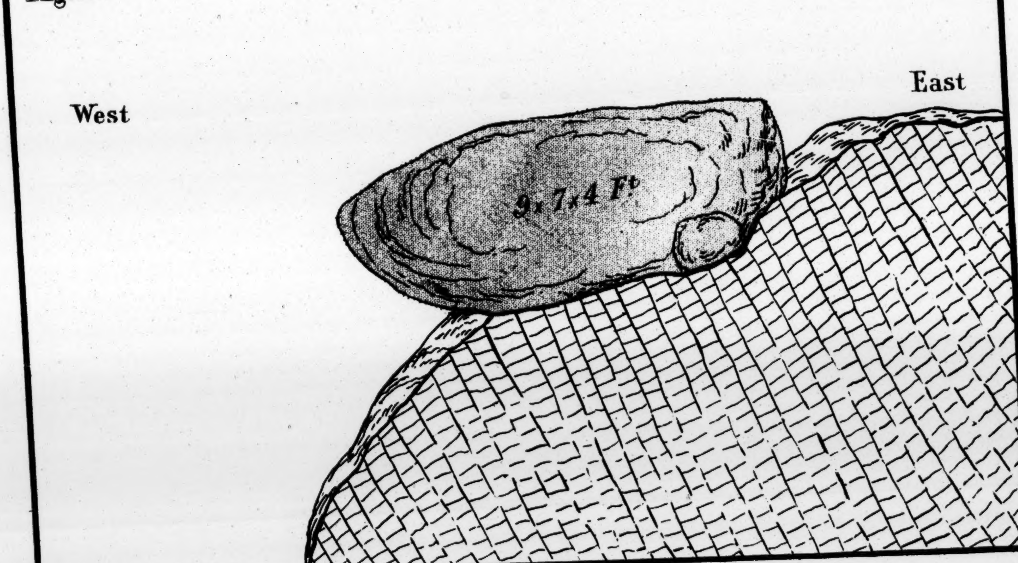


Fig. 44.

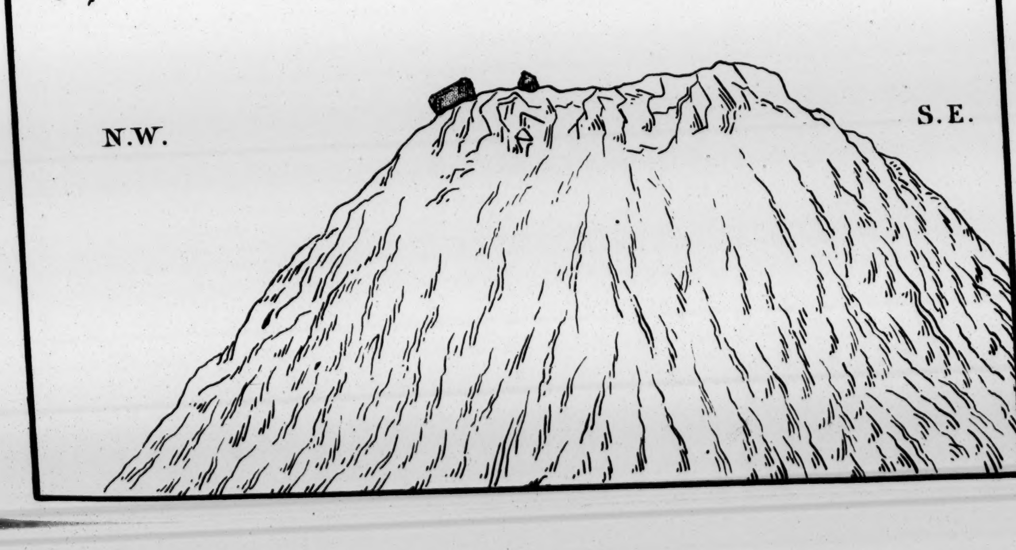


Fig. 45.

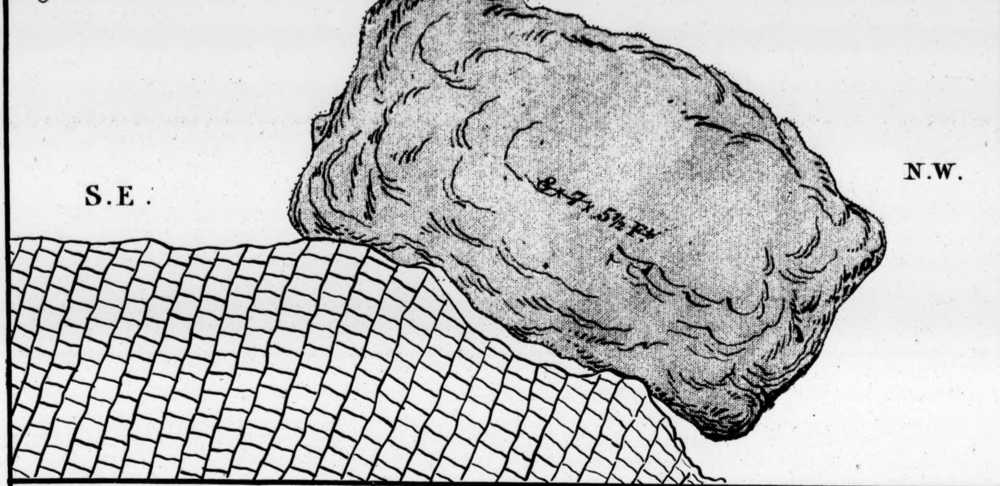


Fig. 46.

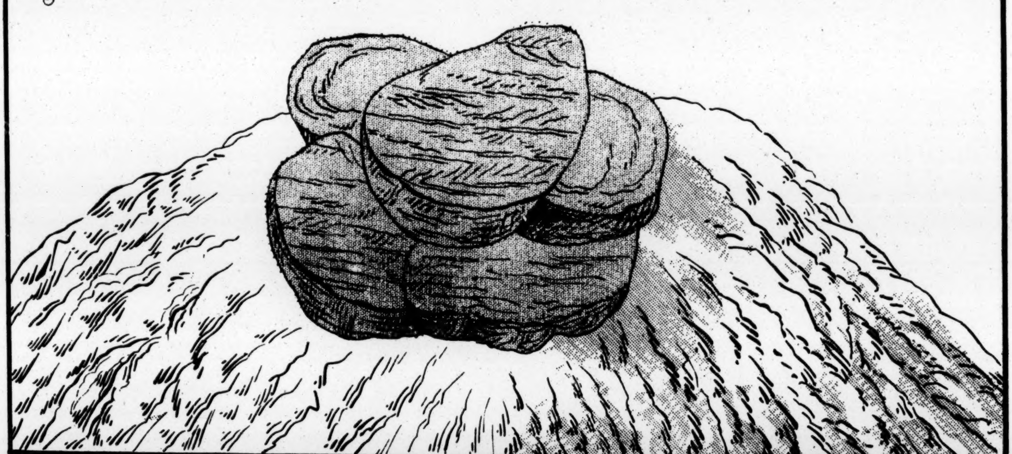


Fig. 47.

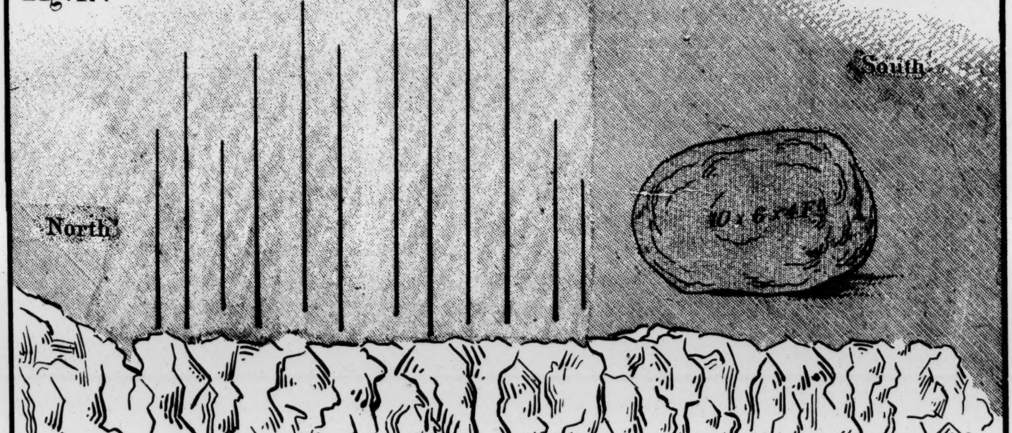
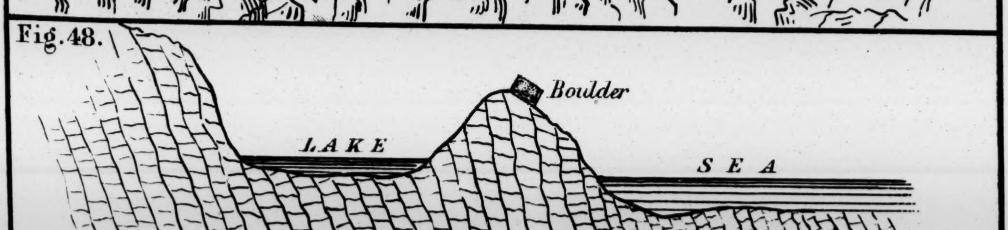


Fig. 48.



the eastward, and projected from the glacier's surface, would the boulder have rested where it fell? Is it not probable that it would have slid down the smooth rock into the sea?

The surface on which it lies, slopes steeply towards the sea, in a direction W. by N.; and under its S.E. end, there are two small boulders which seem to have obstructed progress in that direction. These circumstances conveyed to the Convener's mind the impression that the boulder may have been brought by floating ice, and been thus landed on the rock which it occupies.

It is right to add that the smoothed rocks, which occur near the shore adjoining the lake, have all the appearance of a great amphitheatre, into which floating ice may have entered, and in which ice may have circulated as in an eddy, abrading the rocks forming the bottom and sides of the amphitheatre.

This view of the matter is not inconsistent with the theory, that before the land was submerged, a glacier had existed in the valley, and formed smoothings and groovings also on the rocks as observed by Principal Forbes.

The Convener, seeing the importance of ascertaining beyond all doubt the true character of the materials forming the site of the "Big Boulder," in Barra (p. 122), wrote lately to Dr MacGillivray of Eoligarry, the tenant of the farm on which the boulder is situated, to request that he would dig under the boulder as far as could be done with safety, and send a written report of what was found. Since these sheets were printed, the Convener has received a letter, from which the following are extracts :—

"Having at length got milder weather, we proceeded to the 'Big Boulder of the Glen,' and made the cuts or drains under it, as you directed, to the depth of three feet on both sides, and also at the west end of the boulder.

"The first substance found for about a foot deep, was black soil or earth and cockle-shells, mixed up with a few stones. Below that, as deep as we could conveniently go, very hard gravel and lumps of stone, extremely firm and difficult to pick out,—I should say, because being so much compressed by the enormous weight of the boulder.

"The rock of the hill did not appear at all on any side, or under the boulder for three feet at least. It seemed resting entirely on soil and gravel; site very high, almost on the surface, so that a spade can be pushed nearly to the centre in one or two places.

"The stone, to even an ordinary observer, would appear to have been brought to its present situation by some agency or other, as the place looks quite unnatural to it."

Notes by William Jolly, Esq., Inverness, on the Transportation of Rocks found on the South Shores of the Moray Firth.

(*Sent to Boulder Committee, October* 1878.)

Along the south shores of the inner portion of the Moray Firth, certain movements of rocks have taken place in geological times which are interesting as bearing on the inquiry into the general transportation of boulders over Scotland. These rocks are, happily, of very distinctive varieties, which renders the question of their source and movements a comparatively easy one. On these, I beg to offer some rapid notes, in connection with the work of the Boulder Committee.

I.—The Granite of the Dirrie More.

At the back of Ben Wyvis, on the road to Ullapool, between the Ben and Strath Vaich, there exists a development of a peculiar granite *in situ*, easily seen in passing along the road. The granite occupies a considerable area in the centre of the valley, and is seen in great extent in the bed of the river, to which it imparts a wild and picturesque character, as the water dashes and foams amongst its projecting masses. The rock consists of the usual ingredients of trinary granite, but its distinctive feature is the existence of lenticular pieces of dark mica, arranged throughout its pinkish mass in pretty regular layers, which give the rock somewhat of the general aspect of a stratified deposit. It is peculiar in general appearance, and is easily distinguished wherever seen by its *kenspeckle* character, even when not broken up. This rock is found scattered all over the country to the eastward of its parent position, and would seem to have been carried down the Blackwater valley in which it is found, and also right through the deep glen which exists in the very centre of the great bulk of Ben Wyvis, and which forms its most distinctive feature as seen from the Dirrie More, or Great Slope, as the long road to Ullapool is called. Thus viewed, Ben Wyvis seems cleft into two mighty masses by this great gorge, and has from this point, perhaps, its grandest and most commanding aspect. This granite is found scattered abundantly all over the Black Isle, where it exists as the most abundant surface rock, being imbedded in the debris and boulder clay that clothes the whole of

its surface. It may be seen in boulders which have been broken up for fencing purposes, showing the interior composition very well, along the road from Conan village to Ferintosh, where it forms the greater part of the dyke that skirts the highway. It occurs right on the summit of the Mulbuie, or Yellow Ridge, which forms the backbone of the Black Isle. It can be seen there to good advantage, along the old road between Dingwall and Inverness, which ran right over the Mulbuie between Conan and Tor Inn, a path which must now be traversed on foot, and which commands a magnificent prospect. These granite blocks are scattered all over the eastern slopes of the Mulbuie, and may be seen on the Black Isle coast of the Moray Firth, as at Avoch, Fortrose, and along the district traversed by the high road leading to Cromarty.

The blocks have been carried across, not only the ridge of the Black Isle, but what is now the Moray Firth, to beyond Elgin, and they may be seen on the coast between Burghead and Lossiemouth. At Lossiemouth, on the high ridge of Stotfield above Branderburgh, several masses may be observed in the dyke above the Public School. I have no notes of its appearance east of this point.

II.—THE LOCH NESS GRANITE.

At the northern end of Loch Ness, on its western side, a large patch of red granite exists along the shore—from a point a little south of Loch End Hotel, at a burn just opposite Dores, to a point about a mile south of the mouth of the Abriachan Burn—and extends westwards from the loch in a triangular outline some two or more miles broad, forming the mass of the high hill between Loch End and Abriachan, which there bounds the loch. This granite is fine-grained and of a light pinkish colour, and is used for commercial purposes, numerous examples of it being to be seen in Tom-na-Hurich cemetery near Inverness, and elsewhere. The smallness and compactness of its component ingredients are its chief peculiarities. It occurs in the abundant gravel deposits to the eastwards of Loch Ness, in Tom-na-Hurich for instance, as noted long ago by George Anderson, the eminent geologist and joint author of Anderson's excellent guide-books to the Highlands; and eastwards of this, on beyond Nairn and Forres. It is found less in large boulders, though it occurs in considerable masses, than as forming part of

the gravel deposits which form so marked a feature on the south shores of the Moray Firth.

III.—THE LIVER-COLOURED CONGLOMERATE.

On the east shore of Loch Ness, opposite this granite, extending from Loch Ashie to a little south of the Fall of Foyers, stretches a high ridge formed of Old Red conglomerate, of which also the great mass of Mealfourvounie on the opposite shores of Loch Ness wholly consists, up to its very summit (3060 feet), which is the highest point attained by this basal deposit of the Old Red of Scotland. This conglomerate, on the east side of the loch, is best seen on the Stratherrick road from Inverness, where it runs above Loch Duntelchaig, south of its junction with the road to Dores, and along the side of Loch Kecklish (Ceo-glash), which lies between Loch Duntelchaig and Bochrubin. Here it forms a series of very striking precipices, vertical, bare, and cracked, overhanging the road and loch, and having a remarkable appearance, arising from their form and composition. This conglomerate happens to contain in great abundance, imbedded in its matrix, a certain dark-purplish or liver-coloured quartzite, in pieces of considerable size. This quartzite is so marked and peculiar that it can be easily distinguished in any boulders in which it occurs, and it seems, so far as I have seen (and I have examined the most of the country minutely), to be peculiar to the conglomerate on this part of Loch Ness; so that its existence in any conglomerate block is a very sure evidence of its parent site. A very good place to see it *in situ* is an abrupt little hill close by the junction of the Stratherrick and Dores roads, crowned by an ancient hill fort, called *Caisteal-an-Duin-Riabhaich*, or the Castle of the Grey Hillock, with rough enclosing walls, easily noted from the highway. The fort is also worth visiting, on its own account, and for the fine view obtained from its summit; and there this liver-coloured quartzite may be well seen embedded in the conglomerate which forms the mass of the hill.

This special conglomerate is scattered to the N.E. of this point, in very numerous masses, onwards beyond Elgin. One peculiarity of this rock is that it is found so frequently in large blocks, often of immense size,—so large that they have attracted the attention of the old inhabitants and have received local names; and

they not seldom occupy conspicuous and elevated positions. They are very abundant, on the flat Old Red Sandstone ridge of the Leys, lying between the valleys of the Ness and the Nairn, where they are frequently very large. The great boulder near the battle-field of Culloden, known as Cumberland's Stone, is formed of it, being rubbed, rounded, and grooved on the upper side; the splendid angular, cubical mass of Tom-Reoch, on the opposite bank of the Nairn near Cantray Doon, one of the largest and finest blocks in this part of the country, is a worthy specimen; several large boulders in the fine woods of Cawdor, one of which, the Grey Stone, stands on the edge of the river, near the junction of the two streams that form the burn of Cawdor, a little above the castle, are composed of it: while, east of this, it is represented by exceedingly numerous blocks, the chief of which are *Clach-an-oidhe*, or Stone of the Virgin, 20 feet × 15 × 9, close by the Public School of Geddes; another, near the top of the Hill of Urchany, at a height of 580 feet, called *Clach-na-Calliach*, or Stone of the Old Woman; the fine boulder right on the crest of the hill, a little to the east of this, called *Clach-nan-Gillean*, or Stone of the Boys, at a height of 690 feet; several big blocks on the high ground of Moyness, one in particular lying close by the roadside below the U.P. Church of Moyness or Boghole; the splendid block on the high ridge on which stands the picturesque ruin of Burgie Castle, east of Forres, a short distance beyond the castle, called the *Douping Stane*, from a burgess ceremony performed on it, as lying on the extremity of the town lands of Forres; and a very large mass, still partly imbedded, on the crest of the hill of Roseisle, perhaps of the same rock. Examples of it may be seen on the south shore of the loch of Spynie, not far from the castle, between Elgin and Lossiemouth, The whole country between Loch Ness and Lossiemouth is literally strewed with pieces of this easily distinguished conglomerate. Several of the larger specimens of it have already been visited, described, and figured by Dr Milne Home, in former reports of the Boulder Committee.

IV.—THE GRANITE OF STRATHERRICK.

In the elevated hollow strath, or plateau, known as Stratherrick, which runs parallel to Loch Ness on its eastern side, occurs a large

patch of grey granite, occupying nearly the centre of the strath. It is very well exhibited near the Roman Catholic chapel, where it occurs *in situ* in large masses, and where it has been worked. It is a granite of very good quality, and has been greatly used for building; and it would be much more used if it were more accessible from lines of public communication. It extends down the pass of Inverfarigaig, where it forms the rock of its upper portion, the lower being the Old Red conglomerate. This grey granite is found in blocks of different sizes, some of them large, all over the country east towards Elgin, intermingled with the conglomerate just mentioned; but it never occurs in such large masses as the conglomerate, which, from its nature and original position, it could not do. It is remarkable that this granite is also found in blocks scattered *over the very top of the ridge of conglomerate between Loch Kecklish and Loch Ness*, already described, sometimes finely perched on its very summits, which range between 1400 and 1500 feet, and I have numerous notes of big boulders of it found there.

V.—THE GNEISS OF STRATHERRICK AND THE MONAGHLEA MOUNTAINS.

Parallel to the line of conglomerate blocks scattered between Loch Ness and Lossiemouth, often intermingled with it and the granite of Stratherrick, but occurring much more abundantly to the east of it, is found a broad band of boulders of grey gneiss. These are of all sizes, frequently large enough to have claimed popular notice and to have received local names, and are often placed in remarkable and elevated positions. The character of the rock may be well seen on the side of the road between Inverness and Farr, in the dyke near the Free Church of Farr, and in the fine group of boulders in the centre of the valley, which forms so striking and interesting a geological feature there. They occur in astonishing numbers round *Loch-na-Clachan*, or the Loch of the Stones, into which the stream from Loch Duntelchaig flows, near the old parish church of Dunlichity. There they form grand and picturesque groups of all sizes and forms, on the east side of the loch and up to the elevated summits of the hills, above 1400 feet high, and where they may often be seen, right on their crests, standing in a serrated line against the sky. Altogether, this is one of the most remarkable aggregations of blocks that I know, and it has already been referred

to by Dr Milne Home, in his valuable paper on Glen Roy. Farther up the Nairn, near Farr House, stretches a long flat plateau of gravel and other debris, which stretches right across the valley, and through which the river has had to cleave its way in the narrow gorge below Flichity Castle. On this plateau is found another striking and numerous assemblage of huge blocks, well worth a visit, often of large size and peculiar forms, scattered singly and in groups, some of them standing erect like great pillars. Frequently these gneiss blocks have been left in remarkable places. On Craig-a-Chlachan, which overlooks the church of Dunlichity, on the west shore of Loch-na-Chlachan, near its top, on the edge of a steep precipice, is poised a block of gneiss 14 feet long, 10 feet in height, which catches the eye of the traveller from all points, and is known as *Clach-na-Fhreiceadan* or *Faire*, or the Stone of the Watch, on account of its elevated station (1120 feet), standing, as it does, like a sentinel, to guard the surrounding region.

To the east of the Free Church of Farr, right on the peaked top of the highest hill seen from that part of the valley, may be observed what seems a shepherd's cairn marking its summit. This provoked my curiosity for years, and this season I ascended the mountain and found that it consisted of a great block of gneiss split in two, and known, from this circumstance, as the *Clach Sgiolte*, or Split Rock. It has been originally a cube of stone, 9 feet square and 5 feet high, now split at two-thirds of its breadth, the larger part having remained in its original position and the smaller having fallen over. It stands nearly 1000 feet above the valley below, and nearly 1600 feet above the sea. Another *Clach Sgiolte*, on or very near the top of the great mountain, overlooking the narrow gorge of Conaglen, near Dunmaglass, at the very head waters of the Nairn, called Ben Dhu Choire, at a height of 2260 feet. This block I have not yet ascended to.*

Another striking example of these gneiss blocks is found beyond the inn of Flichity above Farr, on the north slope of the finely crested ridge that lies between the valley of the Nairn and Loch Ruthven. It is called *Clach-a-Bhonat*, or the Stone of the Bonnet. This is a very large block, worth a visit. In this part of the valley of the Nairn, numerous other blocks occur singly and in groups in

* There is another *Clach Sgiolte*, about 1¼ mile from the source of the Findhorn, called the Eskin, some 2070 feet above the sea.

the bottom of the valley, and high on its sides up to the crests of the enclosing hills, on which they may be seen standing against the sky line.

Farther down the valley, below Daviot and not far from the mansion of Nairnside, a very fine boulder is perched on the top of a steep rock overlooking the river, on its eastern bank. It is 21 feet × 12 feet × 15 feet in height, and forms a fine object as seen from below, from the peculiarity of its position and great size. It is called *Clach-an-ullaidh*, or the Stone of the Treasure-Trove, from the prevalent idea that treasures lie concealed under such remarkable rocks; for there are numerous blocks with the same name and tradition, in various parts of the Highlands.

On the same side of the Nairn, and not far from the block just mentioned, another is found, high up on the hill bounding the valley, and seen against the sky from below, very distinctly so from the Cumberland Stone, and from the road to the far-famed Clava, with its cairns and standing-stones. It is called *Clach-a-nid*, differently interpreted to be the Stone of the Nest, an unlikely meaning, and more probably the Stone of the Whistle, as the point to which the herd ascended to whistle and call on the cattle scattered over the hill slopes there, when he went to drive them home for the night. It is a very fine block, measuring 21 feet × 21 feet × 20 feet high, and has a commanding position (950 feet), with a splendid prospect, over the pastoral Nairn, away to the distant N.W. Highlands.

There are numerous other blocks of the same gneiss worthy of mention, but the foregoing will suffice as examples. They are found extending to the eastwards like the rocks already mentioned.

VI.—THE KINSTEARY GRANITE.

Near Nairn, on the estate of Kinsteary, occurs a considerable development of granite, of distinctive character and great value. It is of a rich flesh-colour, and its chief feature is the existence of fine large crystals of orthoclase felspar, which give it its special beauty, approaching in appearance as it does to a rich-coloured marble. It has only been recently worked for the market, but has already taken a high place, and is largely used in London and elsewhere for fine ornamental purposes. It may be seen *in situ*, quarried at different places, at a short distance from Nairn, on the road to Ardclach.

This peculiar granite, which can easily be distinguished wherever it occurs, is found abundantly to the eastwards of its original position. In all the dykes and houses in and round Auldearn, and all over the Moyness district, it may be seen as the most abundant rock. It extends eastwards beyond Forres, gradually lessening in amount but still abundant, over the flats of Kinloss and up on the high ridge of Burgie to its summit above the *Douping Stone*, and beyond Elgin to Lossiemouth and further east. Pieces of it may be seen on the shores of Loch Spynie near the blocks of conglomerate already mentioned.*

The foregoing are the chief examples of travelled boulders found on the south shores of the Moray Firth. Many others occur, but these have been mentioned because they consist of rocks of a more or less pronounced character, easily distinguished where seen; therefore furnishing important evidence as to the direction and extent of the transporting agents. From the map, it will be seen that the general direction of movement of these blocks has been eastwards, but chiefly from S.W. to N.E., parallel to the trend of the coast of the Moray Firth at this part. None of these rocks are found to the *west* of the points *in situ* where the parent rock is found; at least, I have found none, and I speak from a pretty extensive knowledge of the district. What the transporting agent or agents were—whether glaciers, or icebergs, or ice-floes, or water currents, or one or more of these together—however interesting and important—it would be foreign to the purpose of the present paper to consider; but that these rocks were carried from their native sources and scattered widely and numerously to the eastwards, over a large extent of country, cannot for a moment be doubted. †

WILLIAM JOLLY,
H.M. Inspector of Schools, Inverness.

* I have no notes of the distribution of these boulders east of Lossiemouth. Mr Wallace, head master of Inverness High School, and a good geologist, tells me that he saw recently large blocks of both the Dirrie More and Kinsteary granites at Buckie in Banff, dug out of the new harbour. It would be interesting to ascertain how far east these easily distinguished rocks have been carried.

† The author purposes entering into greater detail in regard particularly to the remarkable carried blocks of the valley of the Nairn, in a special paper on the glaciation of that valley.

I.

Observations on Boulders and Drift on the Pentland Hills.

By Alex. Somervail, Stationer, Edinburgh.

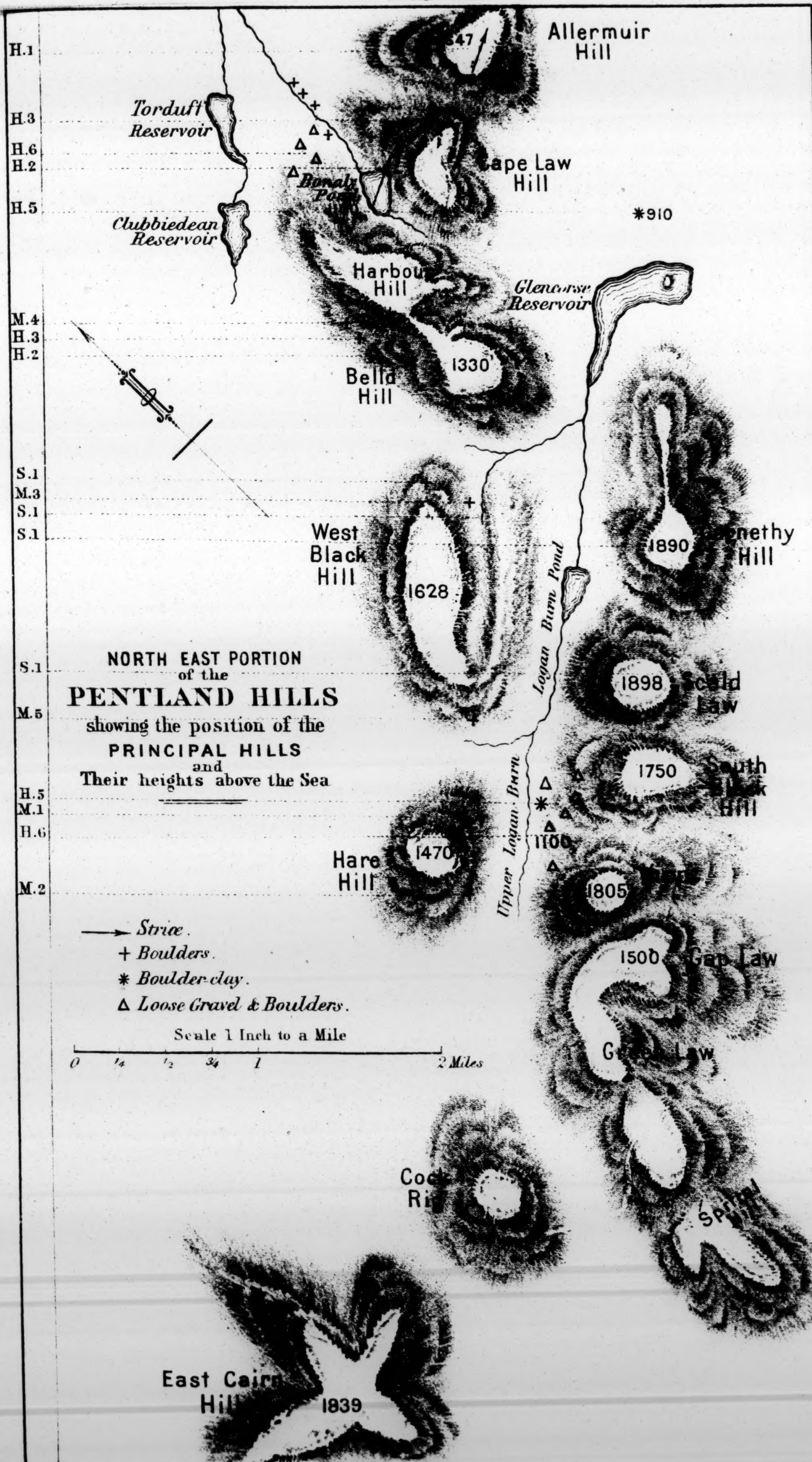
Besides the boulders described by the late Mr Charles Maclaren in his "Geology of Fife and the Lothians," and also by Professor Geikie in the "Edinburgh Memoir of the Geological Survey," as having been carried from the Highlands, there are others which would indicate a transport from a different direction.

On the highest summits of the Pentland Hills (Scald Law, Carnethy, South Black Hill, North Black Hill, and others which are composed of various varieties of porphyrites) are found numerous boulders of fine conglomerates, grits, and sandstones, intermingled with a few boulders of quartz, greenstone, and other rocks, all partially or entirely covered by a deposit of peat, which in some places on and near the summits of the hills attains a thickness of nearly six feet. The sandstone boulders vary in size from mere fragments up to large masses which I was unable to dig up. They are common on the very highest point of Carnethy (S. 1),* more so on Scald Law (the highest of the range) and South Black Hill, and still more abundant on the West or North Black Hill. They are smaller in size and less numerous as we approach the hills in the neighbourhood of Edinburgh—viz., towards the east.

On a careful examination of the above-mentioned sandstone boulders, with regard to mineral composition, texture, and colour, there can be no doubt that they have been derived from the sandstone strata which form the Cairn Hills. The highest point of the Cairns is 1844 feet, or 46 feet below the level of Carnethy, and 54 feet lower than Scald Law, which is 1898 feet above the sea-level.

It would follow from this, that the transport of the sandstone boulders has taken place from S.W. to N.E., or very near this direction. There are other indications which confirm this movement. Mr John Henderson has, in the "Transactions of the Edinburgh Geological Society," vol. ii. page 365, described the occurrence of a

* A plan of a portion of the Pentland Hills, to illustrate Mr Somervail's and Mr Henderson's notes, is appended. On this plan the localities mentioned by Mr Somervail and Mr Henderson are indicated by the letters S. and H. respectively.



Lithog. by W & A K Johnston Edinburgh

large slab of sandstone lying in the gorge of the Bonally Burn, derived from beds of the same rock about half a mile to the S.W.

In a deep cutting recently made in the boulder clay at Alnwick Hill, near Liberton, I observed many boulders of Old Red Sandstone, which must have been carried from the vicinity of the Carlops, where the same rock occurs *in situ.* There were also boulders of various varieties of porphyrites, which form the hills to the S.W. The same remarks hold good with regard to boulders I saw dug from very deep excavations made two years ago at Seafield, near Leith, all bearing out a transport of some kind along the trend of the Pentlands, or from S.W. to N.E.

A fact in connection with the Old Red Sandstone boulders I observed at Alnwick Hill appears worth recording. Many of these boulders were very round and smooth, so much so that they suggested the idea that the agent which transported them to their present position could not have produced this effect during transport, as the distance from their source is so very small, but in all likelihood found them worn and rounded before being carried along.

NOTE ON THE BOULDER CLAY.

There is, in my opinion, no true till or boulder clay resting on any of the Pentland summits. What has been described as such by Dr Croll on the top of Allermuir Hill seemed to me simply a peaty soil formed by the decomposition of the underlying rock and debris, and the decay of vegetable matter, making up a heterogeneous deposit which, however, has no connection with the true boulder-clay occurring at lower levels.

II.

NOTES ON DRIFT AND GLACIAL PHENOMENA ON THE PENTLAND HILLS.

By JOHN HENDERSON, Curator of the Phrenological Museum, Edinburgh.

The following phenomena were noted by me during a number of visits I made to the Pentland Hills; but as my chief object then was to examine the older rocks, my observation on the recent deposits are by no means complete.

Striated Rock Surfaces.—Only two localities were observed. Dr Croll, in a paper on "The Boulder Clay of Caithness," first made known that he had discovered a striated rock on the top of Allermuir Hill, at a height of 1647 feet above the sea. I visited Allermuir Hill some time after this discovery, and was fortunate enough to find a portion of the striated surface. The rock of the summit of the hill is felstone, very much weathered and broken up, and it is only in the little hollows, which are covered with a blackish earth, that indications of rubbed or scratched surfaces are found. The portion I discovered, although it was only a few inches square, was finely striated, and I had no difficulty in making out the direction of the striæ, and the direction from which the striating agent had come, which was about W.S.W. (See Plan, H. 1.) The other locality I discovered during a very dry summer, when the water in Bonally Pond was very low. The striæ occur here on a reddish sandstone, which crops out along the south-east side of the pond, at an elevation of about 1100 feet above the sea (H. 2). There is here a much larger surface of striated rock than on Allermuir Hill, but it is mostly always covered by the water of the pond. I had an opportunity, however, of seeing a portion of it again last summer. I then took the direction of the striations, and found them, as on Allermuir Hill, W.S.W. I may remark that this agrees with the direction of the striæ on the rocks of at least twenty localities that I have examined in the neighbourhood of Edinburgh, and in no instance in this neighbourhood have I observed the rocks striated in a direction N.W. and S.E.

Boulders occur at all heights up to 1400 feet, and all sizes up to 10 or 12 tons. Several very large ones lie on the north side of Capelaw Hill, at about 1200 feet above the sea (H. 3). They are of a dark crystalline greenstone, unlike any of the igneous rocks in this district. Further west, on the west side of Harbour Hill, there is a great number of smaller blocks of the same greenstone (H. 4). They appear to me to lie on about a uniform level along the hill side, at about 900 or 1000 feet above the sea. The prevailing boulders in the northern portion of the hills are of greenstone, while those further to the S.W. are mostly sandstone.

Boulder Clays.—I have observed two localities where these occur in considerable quantities, one at the north-west corner of Glencorse

Reservoir, at an elevation of 900 feet (H 5). It is a stiff reddish clay, full of well rubbed and scratched stones, and differing in no way from the boulder clay of the lower districts. The other locality is about three miles to the S.W. of this, in the same line of valley between the hills, at an elevation of about 1100 feet. It is of the same character as the last, but is covered by a great deposit of gravel and boulders, which extends across the broad valley between Hare Hill and South Black Hill (H. 6).

Another large deposit of gravel and boulders is at the mouth of the broad valley in which the Bonally Pond lies, at an elevation also of 1100 feet above the sea. This deposit encloses some very large boulders of greenstone (H. 6).

III.

The Convener appends to the foregoing Notes by Messrs Somervail and Henderson, the References by the late Charles Maclaren, by Professor Geikie, and Mr Jas. Croll, to Striæ and Boulders on the Pentlands, as the localities are embraced in the same map.

1. Mr M'Laren, in his "Geology of Fife and the Lothians," states:—

(1.) "There are few opportunities of observing 'groovings' on the Pentland Hills. I noticed them, however, at Westwater of Dunsyre, on the top of a thick bed of hard sandstone, from which 12 or 14 feet of alluvium had been removed. The dressings pointed exactly east and west; and the evidence was the more satisfactory, as the direction of the stream on whose bank the rock was situated, and of the valley in which the stream flowed, was south and north. They were very distinct, the larger groovings being about $1\frac{1}{2}$ inch broad, and $\frac{3}{10}$ths of an inch deep. The locality must be 800 or 900 feet above the sea" (page 294).

(2.) Travelled blocks are important in two respects:—*first*, as indicating the action of currents or other transporting agents no longer operating; and *next*, as illustrating changes which have taken place subsequently to their deposition in the spots where we find them.

a. "In the Pentlands there is a boulder of mica slate, weighing 8 or 10 tons, on the east end of Hare Hill (see plan annexed, M. 1). It reposes on the surface of the west side of the glen leading north from Habbies How to Bavelaw, on a declivity about 80 feet above the bottom. The nearest spot from which this mass could be derived is the portion of the Grampians about Loch Vennacher or Loch Earn, 50 miles distant" (page 301).

Further, this block tells us that the surface of the hills where it now rests must have been in a different condition when it was deposited. It lies on the side of a declivity, where a large stone, either hurried hither by a current, or dropped from an iceberg, would not stop, but roll down to the bottom of the valley. The reasonable inference is, that the valley between Hare Hill and North Black Hill was then filled with "materials which have since been washed away" (p. 302).

b. Half a mile south from this, three greenstone boulders of 2 or 3 tons weight each are lying on the edge of a precipice, about 200 feet above South Burn. (See plan, M. 2.)

These have certainly travelled some miles, and the bed of clay seen below them is no doubt a remnant of that which then filled up the ravine, and prevented them descending to the bottom.

c. On the east end of West North Black Hill there is a sandstone boulder of 8 tons weight. (See plan, M 3.)

This block may not have travelled far. But it rests on a surface as steep as the roof of a house (inclined both above and below at 45°), and about 400 feet above the bottom of the valley.

It is impossible that it could be dropped here, or brought to the spot by a current, without descending to the bottom, unless sustained in its place by matter since removed.

This single block informs us that the ravine about 100 yards wide at the surface of the marsh, which separates Black Hill from Beild Hill, must then have been filled up with alluvial matter to the height of 400 feet at least above its present bottom, which is probably 50 feet above the true bottom in the rock (page 302).

d. On the south declivity of Harbour Hill, about 300 feet above the level of the Compensation Pond, there is a very large boulder of greenstone weighing 12 or 14 tons. (See plan, M. 4.)

The surface it rests on is not steep. But the boulder must have

travelled many miles; for there is no greenstone of the kind in the hills, and none near them, except in situations 500 or 600 feet lower.

This block has probably been transported in the same manner as the mass of mica slate (*a* above).

e. The same remarks apply to a greenstone boulder lying half a mile N.W. of Logan House, on the south side of West Black Hill, about 1400 feet above the sea. It is of 12 or 14 tons weight. (See plan, M. 5.)

There are many others in elevated situations of 3 or 4 tons weight.

The substance is generally greenstone, the least brittle probably of all rocks, and of course the best fitted to resist fracture. Nearly all the blocks have their angles rounded off.

f. On the banks of Eight Mile Burn, in the low ground, there is a mass of alluvium about 100 feet thick, containing hundreds of trap boulders of all sizes up to 10 tons weight. It consists of two beds,—the older, a blue unctuous clay, the newer a red clay. The large blocks are chiefly in the latter.

There are many similar travelled blocks in the burn flowing from the old Reservoir to Bonally, and probably in all the streams of these hills (page 303).

2. Professor Geikie, in his Memoir "On the Geology of the Neighbourhood of Edinburgh," published in 1861, observes (1) that "boulder-clay lies along the north-west flanks of the Pentlands, rising to a level of at least 1300 feet."

When the clay has been recently removed, we usually find the rock below polished, grooved, and scratched in a direction nearly E. and W., or E.S.E. and W.N.W. These markings even remain distinct on hard greenstones which have remained exposed to the weather for an indefinite period.

The parallelism of the striations throughout the present district shows that the floating ice must have moved in a pretty uniform direction; and that it was from the west is rendered clear by the striation of the western face of the hills, by the great depth of drift on their eastern sides, and by the fact that the transported boulders, when traceable to their parent rock, have been carried from west to east (page 126).

(2.) Of boulders which have undoubtedly been transported either from Cantyre or the Grampian Highlands, I may refer to the mass of mica slate about 8 or 10 tons, on the S.E. side of Hare Hill above Habbie's How, which was first noticed by Mr Maclaren.

(3.) On the other side of the valley, on the S.W. slope of North Black Hill, several smaller masses of white quartz rock occur, fully 1300 feet above the sea-level.

Masses of gneiss, mica-slate, and a hard metamorphic conglomerate, are found in tolerable abundance all over the district.

3. Mr Croll, in "Climate and Time," gives the following observations:—

"On ascending *Allermuir Hill* (1617 feet), Mr Bennie and I found its summit ice-worn and striated. The striae were all in one uniform direction, nearly east and west. On examining them with a lens, we had no difficulty in determining that the ice which affected them came from the west, not from the east. On the summit of the hill we also found patches of boulder clay in hollow basins of the rock. At one spot it was upwards of a foot in depth, and rested on the ice-polished surface. Of 100 pebbles collected from the clay, just as they turned up, every one, with the exception of 3 or 4 composed of hard quartz, presented a flattened and ice-worn surface, and 44 were distinctly striated. A number of these stones must have come from the Highlands to the north-west.

"On ascending *Scald Law* (1808 feet), 4 miles S.W. of *Allermuir*, we found in the debris covering its summit hundreds of transported stones of all sizes, from 1 to 18 inches in diameter" (pp. 441, 442).

2. Remarks on the Boulder Report by the Convener of the Committee, read (in the absence of Mr Milne Home, Convener), by Mr Ralph Richardson, Member of Committee.

This Report contains information applicable to three districts of country, namely—

1. Pentland Hills.
2. Morayshire.
3. Islands of the West Coast, and part of the Mainland.

1. Pentland Hills.

The impression hitherto had been, that the boulders on these hills indicated a movement exclusively from the north-west; and there is no doubt that the mica slate boulders on these hills indicate such a direction; but Messrs Somervail & Henderson, in the notes contained in this Report, have discovered a separate movement from the west-south-west, by the occurrence of certain sandstone blocks, which they think can be traced to a particular hill or hills in the Pentland range. This point is so important, that it is hoped further inquiry may be made regarding it.

2. Morayshire.

The boulders in this country are described in a very interesting Report by Mr Jolly, Inverness, a member of the Committee. Mr Jolly's concluding paragraph deserves notice. He says, "None of these boulders are to the *west* of the points *in situ* where the parent rock is found—at least I have found none, and I speak from a pretty extensive knowledge of the district. What the transporting agent or agents were, whether glaciers, icebergs, ice-floes, or water-currents, or one or more of these together, however interesting and important, it would be foreign to the purpose of the present paper to consider; but that these rocks were carried from their native sources, and scattered widely and numerously to the *eastwards*, over a large extent of country, cannot for a moment be doubted."

3. Islands of the West Coast, and part of the Mainland.

It will be seen from the Report that my own personal survey last summer was chiefly among the islands, which, commencing with Iona at the south, stretches through the Western Hebrides to the north end of the Lewis, a distance of 120 or 130 miles. I selected these islands for two reasons:—1st. Because the boulders on them would be in their original undisturbed positions; 2d. Because one of the agencies by which transport of boulders has hitherto been most commonly explained, *i.e.*, local glaciers, could hardly be adopted for these island boulders. The highest mountain in any of these islands does not exceed 2000 feet, and on most of the islands the height of the hills does not exceed 500 feet. Moreover, even in the

hilliest districts, there are no valleys in which glaciers could have been formed. Therefore, in studying the question of boulder transport, I thought the problem would be simplified when one of the explanations, and that the most commonly received, was inapplicable. In this view of the matter, I am glad now to find that Mr James Geikie, the well-known persistent advocate of glacier agency, concurs. Since my visit to the Hebrides, I have read a most interesting report by him, published in the "Transactions of the London Geological Society" for October last. In this report Mr Geikie describes a visit he had paid to the Western Hebrides. Referring to South Uist, the highest hill in which (Mount Hecla) reaches to about 2000 feet above the sea, Mr Geikie says—"The nature of the ground is not such as would *favour the formation of local glaciers of any importance.* If such ever hung on the southern slope of the mountain, they must have been of insignificant size, for they have left no moraines behind them."—(Page 842.)

So also, in referring to North Uist, Mr Geikie says—"I saw no trace of terminal moraines. In short, evidence of *local glaciation* appears to be wanting, and if any local glacier ever did exist, it must have been of insignificant dimensions."—(Page 848.)

The question remains whether the Islands suggest any other agency than local glaciers. In examining the Report, it will be found that the following positions seem to be established:—

Boulders.

1st. The great majority of the boulders are situated on the slopes of hills which *face the north-west.*

2d. Though there are boulders in all parts of the Islands, they are more numerous on the *West sides of the Islands* than elsewhere.

3d. Multitudes of boulders occupy *positions* which they could not have come into, except from the north-west.

4th. In a few cases, the *parent rocks of boulders were discovered.* On the mainland, near Gair Loch and Loch Maree, several boulders of a peculiar sandstone rock occur, which must have come from north-west, as it is only in that direction that there are rocks of the same description.

Also on the north end of the Lewis, granite boulders occur traceable to hills situated to the westward.

As to boulders on the west coasts, if they came from the north-west, there can of course be for them no parent rock in this country.

Rock Surfaces.

The Report contains information on other points bearing closely on the question of boulder transport.

I was particularly struck with the fact, that the bare rocks of the Islands, and also on the mainland, were *smooth* on the sides facing the *west*, but *rough* on the sides facing the *east*.

In some parts, the rocks had evidently been ground down under the operation of heavy bodies moving over them. *The direction in which this grinding had taken place* was in many instances shown by long lines of furrows and striæ, which were uniformly in the direction of north-west and south-east.

Mr Geikie, in his first paper on the Hebrides, read to the London Geological Society in 1873, notices one or two of these striated rocks, and admits the direction to be as now stated. He asserts very firmly, that the striating agent *must have moved from the south-east.* It appeared to me, however, on a minute examination of the individual striæ, that the agent which produced them moved from the *north-west,* inasmuch as the striæ or ruts were generally deepest at the north-west ends, and faded away at the south-east ends.

In two cases of these striated rocks, I saw clearly what had been the *tools* which produced the striæ. The rock was being uncovered by work-people for the sake of obtaining road materials. The covering of the rock consisted of a sandy clay, having imbedded in it angular pebbles of quartz, granite, and other hard rocks. If these materials were pushed and pressed over the rock, there could be no doubt what the effect would be.

Submarine Banks.

Another set of phenomena bearing on this subject, is the existence of gravel and clay beds of undoubted submarine formation. I visited a brickwork near Stornoway, the clay of which contains fragments of sea shells, at a height of 250 feet above the sea. I heard of there being similar beds for miles along the coast on both

sides of the Butt of Lewis, but I was unable to visit them. I learn that Mr James Geikie had not only seen these clay beds, but found that some of the shells in them were of an Arctic type.—(See Report, p. 37.)

There are also in the north part of the Lewis, long ridges and high mounds of gravel, sand, and mud, which must have been formed by the action of water; and it deserves notice that some of the longest of these kaims run in a north-west and south-east direction.

In connection with the smoothed rocks, and these submarine formations, it is not unimportant to remark that many of the boulders must have come at a *subsequent* period; for they lie *upon* the striated rocks, and also *upon the kaims and gravel mounds.*

Now, the question is whether, in any part of the world, we find phenomena analogous to the facts brought out in this Report?

In Sir George Nares' account of his recent Arctic voyage, the following account is given by Captain Fielden, the Naturalist of the expedition (vol. ii. page 343):—

"*Sea-ice* moved up and down by tidal action, or driven on shore by gales, was found to be a very *potent agent* in the *glaciation of rocks and pebbles.* The work was seen in progress along the shores of the Polar Basin. At the south end of a small island in Black-cliff Bay, lat. 82° 30′ N., the bottoms of the 'hummocks, some 8 to 15 feet thick, were studded with hard limestone pebbles, which when extracted from the ice were found to be *rounded and scratched* on the exposed surface only.'

"On shelving shores, as the tide recedes, the hummocks, sliding over the subjacent material down to a position of rest, make a well-marked and peculiar sound, resulting from the *grating of included pebbles with the rocky floor beneath,* or in some cases on other pebbles included in drift overlying the rock."

Sir George Nares, on landing on Norman Lockyer's Island, found the low part for some 300 feet above the present sea-level a succession of raised beaches. "The rock is composed of Silurian limestone. On the summit of a hill 900 feet high, *the whole surface of the exposed rock is marked with ice scratchings,* in a north and south direction."—(Vol. i. page 85.)

A case exactly parallel is mentioned by Sir Charles Lyell, who, when travelling in the Bay of Fundy, North America, fell in with

a large surface of flat sandstone rock on the sea-beach, containing striæ and furrows, of which he gives a diagram, and which he was satisfied had been formed by hard stones fixed on the bottom of floating ice, or pushed before it. At the place in question, the tide rises from 40 to 50 feet, and flows at the rate of ten miles an hour, so that the work done when the sea covered the rock, became visible when the tide was out. — ("Travels in North America," by Sir Charles Lyell, vol. ii. page 174.)

In Mr Campbell's "Short American Tramp," several similar cases on the shores of Labrador, of rocks not only ground and smoothed, but also striated, are given (pages 53, 94, and 107). He mentions also the following fact:—"The effect of heavy ice on the water-line is here conspicuous. A berg about 40 feet out of water was aground at the back of one steep island. It seemed to have taken the form of the rocks, against which it was ground by a heavy swell. *The ice was actually rubbing the stone for that height above water, and for* 400 *feet under it.* It was moved by all the power of an Atlantic wave. *Along the whole coast, for a height of from* 40 *to* 50 *feet, an irregular zone of rock is thus scoured bright and smooth.*"—(Page 93.)

I have thought it right to quote these authorities, because of the strong opinion recently expressed, in more than one influential quarter, against the possibility of rocks being ground, smoothed, and striated by floating ice.

One thing is clear, that in the Hebrides the sea must have stood at a higher level at former periods, and that the sea had an Arctic temperature. But on the mainland of Scotland, there are tracts of what appear to be sea-beds of gravel, sand, and clay, up to a height of at least 2000 feet. Reference may be made to Arctic shells on Snowdon, and near Macclesfield, at nearly the same level, in beds of clay and gravel. Along with these facts, it must be remembered that boulders have been found on our Highland hills, even up to 2000 feet, and in some cases upon what are unquestionable submarine deposits. In this respect Scotland presents nothing different from what exists elsewhere. In Norway, Sweden, and North America, there are in like manner boulders lying on what are now admitted to be submarine deposits at very high levels. To this fact Mr Croll, in his highly speculative volume called "Climate and

Time," makes the following reference :—" In every part of the globe where glaciation has been found, evidence of the submergence of the land has also been found along with it." "The submergence of our country would of course have allowed floating ice to pass over it, had there been any to pass over; but submergence would not have produced the ice, neither would it have brought the ice from the Arctic regions, where it had already existed."—(Page 390.)

Of course, there must have been some oceanic current from the north-west sweeping over this part of Europe, and which continued from time to time, as the sea fell, bringing boulders to be deposited from ice-floes on the hills. Where the boulders came from, cannot at present be even conjectured. The fact only is established that, when the boulders came, the sea stood at least 2000 feet above its present level, and that there was a north-west current, with floating ice, which brought the boulders.

It is hoped that this boulder inquiry will continue. There is now more than geological interest attaching to it, for the facts seem to throw light on important astronomical questions connected with the physical condition of our planet. Mr Croll's theory is, that at one period, ice had accumulated at the North Pole to the extent of three or four miles in thickness, which would of itself cause an elevation of the sea, for reasons explained by him, and resting apparently on sound principles.

Before concluding these remarks upon the Hebrides boulders, and upon the evidence they afford of a transport from the north-west, I wish to refer to a confirmation of these views which I have had much pleasure in finding from the last Report of the Boulder Committee of the British Association. In this Report an interesting account is given of individual boulders and groups of boulders in Leicestershire. In most of the cases mentioned, the parent rocks have been discovered, and in all these cases, *these parent rocks are situated to the north-west of the boulders.*

With regard to the general direction of the agency concerned in the transport of boulders, and the smoothing of rocks in the districts embraced in the Report, which is shown to have been from W.N.W., it is important to remark that there are exceptions, and to note the circumstances on which these exceptions occur.

In two parts of the Lewis, where hills prevail, the movement, as indicated by the positions of the boulders, and the smoothed surfaces of rocks, has been from W.S.W. At these places (page 26 of Report, near foot, and page 20, near top,) it will be observed that there are low-lying narrow defiles or elongated valleys, forming grooves through the country, whose general axis is W.S.W., and with rocky sides.

My idea is, that whilst in the *higher* parts of the country the general traces of a W.N.W. current is everywhere distinct, in *low-lying* valleys, the direction of the current would change, in correspondence with the axis of these valleys. Hence, in valleys, the positions of the boulders are often not the same as at higher levels.

This remark probably applies to some of the boulders reported on by Mr Jolly of Inverness. Thus the Derrie More granite boulders, traceable even as far east as Elgin and Lossiemouth, indicate transport from about W.N.W. On the other hand, the boulders, whose parent rocks are situated on the hills forming the sides of the Great Glen (viz., Caledonian Canal), have moved, not E.S.E. (the normal direction), but E.N.E. There can be no doubt that when the sea stood at a height of say 2000 feet above its present level, and with a general oceanic current from the W.N.W., the current in *Glen-na-Albin* itself —*i.e.*, between the walls of the valley—would be in the line of that valley, forming a deep fissure across the country, running about N.E., and that the force of this abnormal current would be sufficient to carry boulders transported through it in a north-easterly direction, till it united with the more general stream from the W.N.W.

Before closing these remarks, I wish to point out, that there are two localities mentioned in the Report which afford evidence that Local Glaciers had existed before the country was submerged. These places are Glencoe and Loch Etive. It is shown in the Report how in the first instance these glens had been scoured out and polished by ice flowing down the valleys, bringing rocks, which exist *in situ* only at the head. It must have been after this period that submergence occurred, because marine deposits of gravel and sand are found in different parts, with boulders resting on them, which undoubtedly came from some distant point in the north-west. These would have been all scoured out by a Local Glacier, had they been deposited at a preceding period.

4. Quaternion Investigations connected with Minding's Theorem. By Professor Tait.

(*Abstract.*)

Minding's Theorem deals with what may be called by analogy the "focal lines," of the system of single resultants of a set of given forces, applied at given points to a rigid body, when these forces are turned about so as to preserve unchanged their inclinations to one another.

Having obtained an exceedingly simple proof of the theorem by quaternions, I next tried to find the locus of the foot of the perpendicular let fall on each of these resultants from the "centre of the plane of centres." The resulting equation is very complex:—but if we extend the data so as to include *every* position of the central axis (whether there is a couple or no), we arrive at a very simple, and at the same time singular, result.

The locus has then the equation

$$\rho = \psi \varpi \psi \alpha,$$

where α is a given vector, ϖ a given pure strain, and ψ *any* rotational strain. This represents a *volume* not a *surface*.

In the statical problem

$$\varpi \alpha = 0,$$

and the locus is the *volume* included between the two sheets of the electric image of a Fresnel's Wave-surface, in which one of the three parameters is infinite. This image has the equation

$$S \rho (\varpi^2 + \rho^2)^{-1} \rho = 0,$$

a surface whose treatment is easy. But when $\varpi\alpha$ does not vanish we have for the boundary of the locus

$$S (\rho - \varpi\alpha)(\varpi^2 + \rho^2)^{-1} (\rho - \varpi\alpha) = 0,$$

which is by no means so simple.

Monday, 5th May 1879.

DR BALFOUR, General Secretary, in the Chair.

The following Communications were read:—

1. The Pituri Poison of Australia. By Dr Thomas R. Fraser, Professor of Materia Medica, University of Edinburgh.

(*Abstract.*)

An opportunity for examining the Pituri of Australia was afforded to the author by Dr Bancroft of Brisbane, who, in 1877, gave him

for that purpose specimens of dry broken leaves of the plant, in the form in which it is used by the natives, and also a small quantity of watery extract.

After describing its use by the natives of Australia, the author advanced reasons in support of Von Mueller's opinion, that Pituri is obtained from *Duboisia Hopwoodii*, and that this plant should be placed in the Solanaceæ.

By a modification of Sta's process for the separation of alkaloids, he obtained from the extract an active principle in the form of a pale, yellowish-brown, alkaline fluid, freely soluble in water, alcohol, ether, chloroform, amylic alcohol and benzole; of a greater specific gravity than that of water; and possessing a burning alkaline taste, and an odour resembling that of both conia and nicotia. A solution in water of this alkaloid and of its hydrochlorate gave precipitates with bichloride of platinum, solution of iodine in iodide of potassium, iodide of mercury and potassium, iodide of cadmium and potassium, iodide of potassium and bismuth, picric acid, bromine water, perchloride of mercury, trichloride of gold, and other re-agents, and several of the precipitates were crystalline. Strong solution of the hydrochlorate gave precipitates with potash and soda.

The chemical characters suggested a close resemblance between pituria and nicotia, which was supported by the examination of the physiological action. The extract and active principle act as local irritants, and produce death mainly by rendering the respiration difficult or impossible. The circulation is, however, also affected, the strength of the cardiac systole being at first increased and afterwards diminished. It was also found that the cardio-inhibitory fibres of the vagus are at first stimulated and then paralysed; that the arterial blood-pressure is at first increased and then greatly diminished; and that, in frogs, the peripheral terminations of the motor nerves are paralysed, and the cutaneous pigment becomes diffused. Contraction of the pupils occurs before death.

When either the extract or active principle is applied directly to the eye-ball, irritation with increased lachrymation is produced, and the pupil becomes for a short time contracted, and afterwards dilated. The last effect was not observed with a specimen of nicotia in the author's possession, and, accordingly, a doubt is

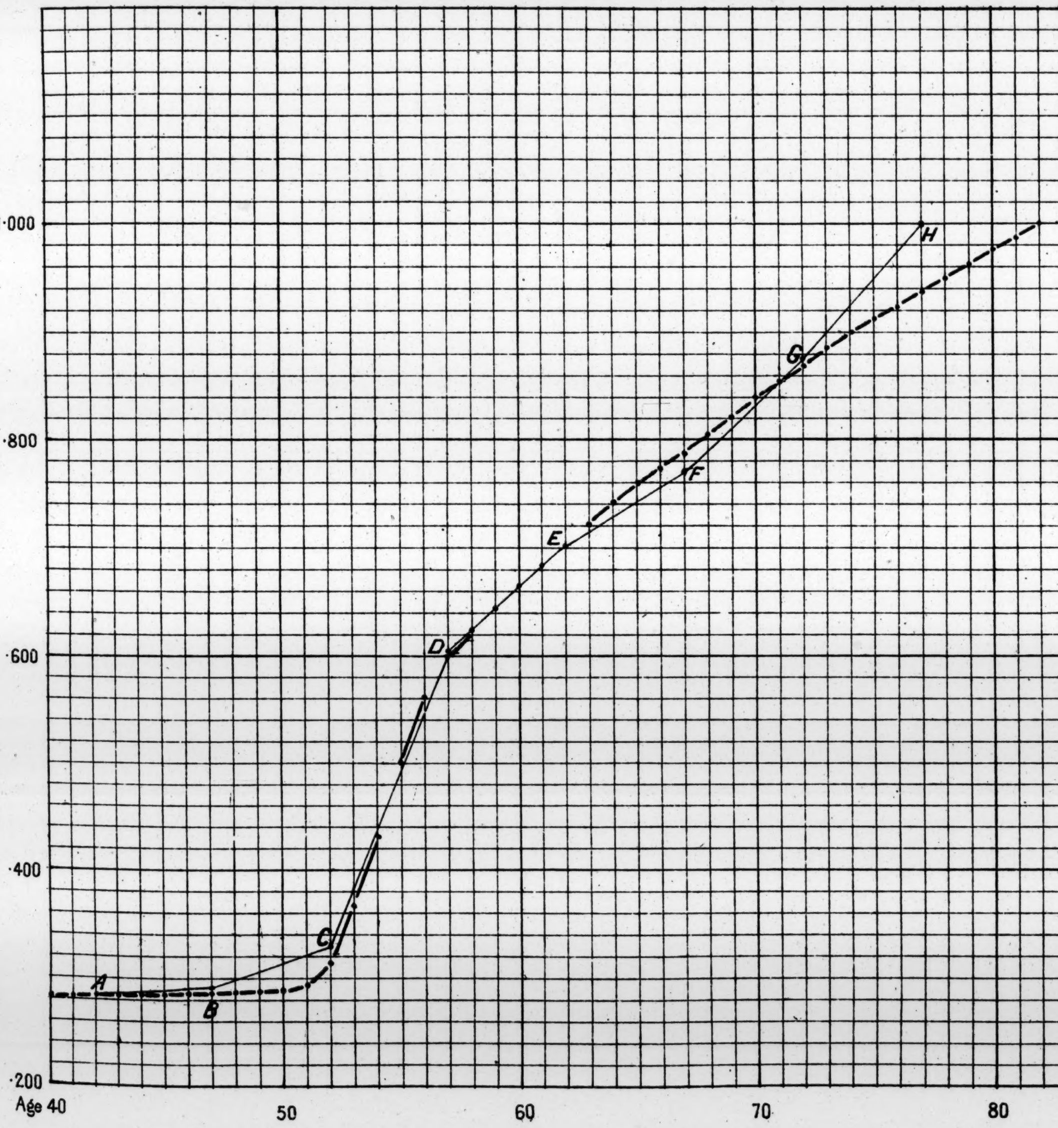
suggested as to the identity of the pituri alkaloid with the alkaloid of tobacco; but it would appear that some observers have noted dilatation of the pupil as a result of the direct application of nicotia to the eye-ball.

It was pointed out as a remarkable fact that the aborigines of Australia should have discovered, and when discovered, placed a high value upon the action of a substance closely resembling in its composition and effects the tobacco so well known to, and so highly appreciated by, millions of the human race.

2. On the Structure and Affinities of the Platisomidæ. By Dr R. H. Traquair.

3. Note on the Probability that a Marriage entered into by a Man above the Age of 40 will be Fruitful. By Thomas Bond Sprague, M.A., F.R.S.E. (Plate XIV.)

When it is desired to disentail a landed estate, it is necessary for the heir in possession, after obtaining the consent of the first substitute heir, to pay to the second and third heirs the estimated value of their expectancy or interest in the estate. In the calculations that have to be made for the purpose of ascertaining this value, the actuary has often to take into account not only the probabilities of life, but the probabilities of marriage and of leaving issue. The heir in possession may be unmarried, in which case he may marry at some future time, and leave a child who would inherit the estate to the exclusion of the subsequent heirs; or the heir in possession may be married but have no children, and the probabilities then to be estimated are (1) that his present wife will have a child at some future time, and (2) that she will die before her husband, that he will then marry a second time, and have issue by his second marriage. Similar contingencies may occur with regard to the first substitute heir. The theory of the calculation of life contingencies is well understood; and much has been done in the way of accumulating marriage statistics and calculating the probability that a man of any age, bachelor or widower, will marry at some future time; but little, if anything, has been


1·000
·800
·600
·400
·200
Age 40
50
60
70
80
A
B
C
D
E
F
G
H

done in the direction of estimating whether the marriage so entered into will be fruitful or not. My object in the present note is to contribute towards the elucidation of this question.

The statistics furnished in the Decennial Census Reports and in the Annual Reports of the Registrar-General, afford the means of calculating the marriage rate among the general population, but these are of no assistance to us in the present inquiry. First, as regards the rate of marriage, it would be clearly unsafe to assume that the rate deduced from statistics as to the general population, of which the working classes form a very large majority, would be applicable to the landed gentry. Secondly, the above mentioned statistics give us no information whatever as to the fruitfulness of the marriages entered into. It is therefore necessary to seek statistics in some other quarter, and statistics very trustworthy and perfectly suitable for our purpose, are found among the records of the British Peerage as contained in the various Peerages published annually. The facts given in them are not so numerous as could be desired for special purposes, but it is of even more importance that our statistics should be accurate than that they should be very numerous. It therefore seems to me that the statistics obtained from a careful examination of the records of the British Peerage may safely be adopted as the basis of our calculations in the present subject. I have accordingly taken the volume of Lodge's Peerage for the year 1871, and gone carefully through it, noting all the cases of marriages of men, whether bachelors or widowers, entered into after the age of 40. The total number of such men, as to whom the necessary information was complete, was 339, of whom 132 were bachelors and 207 widowers. These may seem small numbers on which to base a general law; but, in default of larger numbers, I think we must do the best we can to see what conclusions may safely be drawn from them. The following table shows the ages at which the marriages were contracted, and how many of those contracted at each age were fruitful or unfruitful. Most of the marriages included in the observations were contracted many years ago, so that the information contained in the volume of Lodge was taken as conclusive as to whether the marriages were fruitful or not. For the comparatively few as to which there seemed a doubt, I referred to the volume of Burke's Peerage, published in 1878. In all cases if a child was

born, I have deemed the marriage fruitful, whether the child survived or not.

Age at which the Marriage is contracted.	Bachelors.			Widowers.			Bachelors and Widowers.		
	No. of Marriages.	Of which were		No. of Marriages.	Of which were		No. of Marriages.	Of which were	
		Fruitful.	Unfruitful.		Fruitful.	Unfruitful.		Fruitful.	Unfruitful.
40	25	19	6	11	8	3	36	27	9
41	15	12	3	7	4	3	22	16	6
42	19	14	5	10	7	3	29	21	8
43	10	7	3	14	12	2	24	19	5
44	6	3	3	10	5	5	16	8	8
45	6	4	2	10	7	3	16	11	5
46	8	5	3	4	3	1	12	8	4
47	8	6	2	8	5	3	16	11	5
48	6	6	...	11	10	1	17	16	1
49	6	3	3	2	...	2	8	3	5
50	2	2	...	7	4	3	9	6	3
51	2	...	2	7	5	2	9	5	4
52	2	1	1	10	10	...	12	11	1
53	3	1	2	8	5	3	11	6	5
54	4	3	1	4	2	2	8	5	3
55	2	...	2	7	3	4	9	3	6
56	...	...	...	9	3	6	9	3	6
57	2	1	1	7	4	3	9	5	4
58	1	...	1	10	5	5	11	5	6
59	2	1	1	3	...	3	5	1	4
60	2	...	2	14	5	9	16	5	11
61	...	...	...	1	1	...	1	1	...
62	...	...	...	4	1	3	4	1	3
63	1	1	...	4	...	4	5	1	4
64	...	...	...	1	...	1	1	...	1
65	...	...	...	7	2	5	7	2	5
66	...	...	...	3	...	3	3	...	3
67	...	...	...	2	1	1	2	1	1
68	...	...	...	...	...	...	...	...	...
69	...	...	...	1	...	1	1	...	1
70	...	...	...	2	...	2	2	...	2
71	...	...	...	2	1	1	2	1	1
72	...	...	...	2	...	2	2	...	2
73	...	...	..	1	...	1	1	...	1
74	...	...	...	1	...	1	1	...	1
75	...	...	...	...	...	...	...	..	...
76	...	...	...	1	...	1	1	...	1
77	...	...	...	...	...	...	...	...	...
78	...	...	...	1	...	1	1	...	1
79	...	...	...	1	...	1	1	...	1
Total	132	89	43	207	113	94	339	202	137

A glance at this table is sufficient to show that the probability

of a marriage being fruitful is less as the age of the husband increases, and the same conclusion appears more plainly when we group the ages quinquennially, as is done in the following table.

Ages at which the Marriages are contracted.	Bachelors.			Widowers.			Bachelors and Widowers.		
	No. of Marriages.	Of which were		No. of Marriages.	Of which were		No. of Marriages.	Of which were	
		Fruitful.	Unfruitful.		Fruitful.	Unfruitful.		Fruitful.	Unfruitful.
40–44	75	55	20	52	36	16	127	91	36
45–49	34	24	10	35	25	10	69	49	20
50–54	13	7	6	36	26	10	49	33	16
55–59	7	2	5	36	15	21	43	17	26
60–64	3	1	2	24	7	17	27	8	19
65–69	...	...	...	13	3	10	13	3	10
70–74	...	...	...	8	1	7	8	1	7
75–79	...	...	...	3	...	3	3	...	3
Total	132	89	43	207	113	94	339	202	137

If we calculate now the percentage of the marriages which are unfruitful in each quinquennium, we get the following results:—

Ages.	Bachelors.	Widowers.	Bachelors and Widowers.
40–44	26·67	30·77	28·50
45–49	29·41	28·57	28·99
50–54	46·15	27·77	32·65
55–59	71·43	58·33	60·47
60–64	66·67	70·83	70·37
65–69	...	76·92	76·92
70–74	...	87·50	87·50
75–79	...	100·00	100·00
Total	32·57	45·41	41·41

Here we see that, on the whole, both among bachelors and widowers, the probability of a marriage being unfruitful increases with the age of the husband. The progression among the bachelors is less regular than among the widowers; but this is no doubt to be explained by the smaller numbers that are under observation. When we take the bachelors and widowers together, the progression

is remarkably regular; in fact so regular, that, notwithstanding the comparatively small numbers observed, we shall be justified in believing that we have here an indication of a law of nature, upon which we may safely base our calculations.

In order to make our conclusions practically serviceable, it is necessary to calculate from them the probability for every age from 40 onwards, or, in technical language, to graduate the probabilities. This I do by a graphic method. In the appended figure I take the abscissa to represent the age, and the ordinate the probability that a marriage entered into at that age will be unfruitful. Thus, for age 42, being the middle of the five ages 40–44, the probability is ·285, and this is represented by the point A. In the same way the points B, C, D, E, F, G, H, represent the probabilities for the ages 47, 52, 57, 62, 67, 72, 77. Then, joining these points by straight lines, I draw a curve which shall follow the general course of the points as faithfully as is consistent with the avoidance of irregularities in its form. Then, by estimating the ordinates of the points where the curve cuts the vertical lines in the diagram, I obtain a first approximation to the adjusted probability for each age, and this is afterwards corrected by a process which it seems unnecessary to describe on the present occasion. The following are the values which I thus obtained:—

Probability that a Marriage entered into by a Man of any Age from 40 onwards will be Unfruitful.

Age.	Probability.	Age.	Probability.	Age.	Probability.	Age.	Probability.
40	·284	51	·295	62	·702	73	·882
41	·284	52	·315	63	·720	74	·896
42	·285	53	·365	64	·738	75	·910
43	·285	54	·430	65	·755	76	·924
44	·286	55	·500	66	·772	77	·937
45	·286	56	·562	67	·789	78	·950
46	·287	57	·600	68	·805	79	·963
47	·287	58	·626	69	·821	80	·976
48	·288	59	·646	70	·837	81	·988
49	·288	60	·665	71	·852	82	1·000
50	·290	61	·684	72	·867		

If we now multiply the number of marriages entered into at any age, by the probability in this table, the product will be the number

of those marriages that may be expected to be unfruitful. Doing this for each age, and adding the products together in quinquennial groups, we get the following comparison of the expected and actual number of unfruitful marriages, the agreement between the results affording a very complete test of the goodness of the adjustment.

Ages.	Number of Unfruitful Marriages.	
	Actual.	Expected.
40–44	36	36·2
45–49	20	19·8
50–54	16	16·5
55–59	26	25·1
60–64	19	18·5
65–69	10	10·0
70–74	7	6·9
75–79	3	2·8
Total	137	135·8

I will not attempt to discuss the various points on which the fruitfulness of a marriage depends. The most important of them is clearly the age of the wife; and consistently with this, we see that the probability of a marriage being unfruitful, increases with great rapidity between the ages of 50 and 60; obviously because a much larger proportion of the wives married by men of these ages are past child-bearing than is the case with those married by men under 50.

It is but very rarely that the information available to the public will enable us to form even a reasonable conjecture whether the absence of issue of a marriage is attributable to the husband or to the wife, but such cases do occasionally occur. For instance, when a man marries a widow of 30 who has already had several children, it may fairly be inferred that it is the fault of the husband if there are no children born of her second marriage. So, again, if there are no children born of a marriage, the wife dies, and the husband then marries a second time and has a family, it may fairly be inferred that the absence of children of the first marriage was not attributable to him. It is obvious that cases of this kind are so very few that we cannot attempt to base any general reasoning upon them, nor is it all necessary that we should do so.

It only remains to mention that in obtaining the probabilities above set forth no account has been taken of the age of the wife at the date of marriage. Our conclusion therefrom will have no application to individual cases where the age of the wife is known, but are only applicable to the cases indicated at the outset, where the men we are considering are not contemplating marriage. In other words, we have calculated the probability that, if a man who is either now married or who is single and is not contemplating marriage, shall hereafter enter into a marriage at a certain age, the marriage will be unfruitful.

The following Gentleman was duly elected a Fellow of the Society:—

John Turnbull, Esq., of Abbey St Bathan's.

Monday, 19th May 1879.

Principal Sir ALEXANDER GRANT, Bart., Vice-President, in the Chair.

1. Notice of the Death of the President of the Society. By the Chairman.

Sir Alexander Grant said:—

Gentlemen,—We cannot pass to the proceedings of this evening without some reference to the calamity which has befallen the Royal Society of Edinburgh, and under the sorrowful impression of which we now meet—the sudden death of our honoured and well-beloved President.

We knew, alas! gentlemen, that his health had been failing of late, and that when, only six months ago, he first took his seat as President of this Society, his vigour was impaired, at all events for the time.

But when the lamp of his spirit blazed up so brightly, in the address which he delivered to the University, less than one month since, and which was received with pleasure and enthusiasm by the students and his colleagues, and all the large audience

that were gathered round—on that occasion, I say, who could have expected that his end was so near? He seemed to exhibit vital force such as might carry him through many a year more upon this earth.

Perhaps, had he listened to the first premonitions of disease, had he recognised the necessity of repose and inaction, this might have been the case. But he was of too ardent a nature to "husband out life's taper to the close," and amidst the regrets and lamentations which have now been called forth, may we not say that there was some consolation in that last public scene? May we not almost say that he was *felix opportunitate mortis?* He died, like a victorious warrior, with the affectionate cheers of the University which he had loved so well still ringing in his ears. He sank surrounded by the hues of a refulgent and happy sunset after a long bright summer day.

I shall only venture, gentlemen, to offer a few words of personal recollection of our friend whom we have lost.

His kindly presence seems to belong to this room, as it does also to the University, and to the very streets of Edinburgh. His sympathetic nature led him always to identify himself with the human interests among which he found himself thrown. As professor of mathematics for forty-one years, he was not only one of the best and most highly appreciated teachers that the University of Edinburgh ever had, but also one of its most loyal members and devoted champions. In University matters he had that true insight which is begotten by sympathy; so that though he was an Englishman, born and bred in an English parsonage, and educated at Cambridge till he was thirty years old, he is acknowledged to have understood the Scotch Universities—better almost than any one else. In his addresses and his conversation he loved to dwell more on the merits than on the imperfections of the Universities of this country, and he earnestly deprecated any reforms which should destroy the essential character of those Universities. He had, in the best sense, a thoroughly academic mind. Indeed, he was the type and model of an academic figure. Of genuine piety; with deep learning in his own subject; with a modest, seemly, and dignified exterior; he was full of bright pleasantry and the sweet amenities of life. His interests were not confined to the Universities; he

adopted and took to his heart the broad land of Scotland; and it was a labour of love with him to assist in administering one of the most important of the educational Trusts of this country. It would be utterly out of place—both on this occasion and for myself—to attempt to speak of the scientific merits which rendered Professor Kelland worthy, by universal consent, to hold the high place of President in this Society. I will now merely recall one or two of his own utterances, still full of meaning for us, extracted from those addresses, which were always so pleasing and always so characteristic of him. Whenever I have listened to or read these addresses, they reminded me of that description of a Roman worthy:

> Venit et Crispi jucunda senectus
> Cujus erant mores, qualis facundia, mite
> Ingenium.

> The pleasant old man, Crispus,
> Whose life and mind were, like his oratory,
> All in a gentle strain.

But there was more than mere gentleness in Professor Kelland's utterances. He had the art of conveying many deep and pregnant truths in apparently light and mirthful sentences. I never knew a lecturer who was at the same time so sunny and so wise. Had his life been prolonged and his health restored, we might have expected him often to delight us from this chair. But it has otherwise seemed good to Providence.

Nineteen years ago Professor Kelland returned to his class after being face to face with death in a terrible railway accident. He had travelled sooner than some thought prudent after the injuries he had received. He said, in an address to his students, "I believed that the path of duty is the safest and the easiest path, and I acted on this conviction when, against the advice of my friends, I came down suddenly amongst you." He spoke then of the deaths of no less than twenty-nine professors which had occurred since he had joined the University, and he added, "but I am spared a little while." In that address he seemed to rise to a survey of human life, especially a life spent in pursuit of science. He paid a noble tribute to the earnest genius of Professor George Wilson, then recently dead, whom he compared and contrasted in a most interesting way with the great mathematician Baron Canchy, and he quoted that beautiful saying, which might almost be considered to

have been the motto of Professor Kelland's life: "The measure of the happiness of a man is the number of things which he loves and blesses, which he is loved and blessed by." From the address which Professor Kelland delivered to us at the opening of this session, I must beg to quote three sentences. The first indicates the spirit in which he accepted the office of President. He said: "To myself this honour has come neither to gratify ambition nor to administer to self-conceit. It has descended on me all unsought, through the kindness of the many friends who have sat with me in this room, and the only emotion it awakens is that of affection and gratitude." In the second sentence which I shall recall, Professor Kelland evinces his warm interest in the rising generation of scientific workers. He says:—"One word which I venture on as both encouraging for the present and hopeful for the future, is the remarkable number of young men who are just entering on their work. In the fasciculus of the Society's Proceedings just issued, I count no less than eleven names of young men just entering on their career of investigation. How many of them have caught their inspiration from contact with those older workers who have been long among us? How many have been drawn out and cheered by the associations of this room." In the last sentence which I shall quote Professor Kelland teaches us how now we ought to regard himself. He says: "The feelings which arise on casting one's thoughts back through twenty years are full of sadness when they fasten on individual members of the Society whose presence at our meetings was a source of pleasure not unmixed with pride, but of sadness, brightened by glimpses of the future, when we think of them as members of a living body, as workers even now in the field which man has been sent into the world to cultivate—the field where truth is to be sought and found." As a member of that living body, as an immortal worker in that field of truth, with "sadness brightened by glimpses of the future," we must now think of Philip Kelland.

It was moved by the Chairman, "That the Society should request the Council to express to Mrs Kelland and family, the great regret experienced by the Society at the death of the President." The motion was carried unanimously.

The following Communications were read:—

2. Why the Barometer does not always indicate the Real Weight of the Mass of Atmosphere aloft. A continuation of the Paper on this subject laid before the Society in Session 1876 and 1877. By Robert Tennent.

Meteorological phenomena are in all cases to be regarded as being both a cause and an effect; owing to this, and also to the imperfect state of our knowledge on this subject, it may be safely asserted that exception proves or tests the rule. Taking up the subject in this point of view, much assistance is in this way to be acquired when attempts are made to explain the phenomena which are under consideration, and hence these negative conclusions can to a large extent be taken advantage of. As an illustration of this, can it be assumed that a barometer placed on the surface of the earth, and which always correctly indicates the amount of pressure on its cistern, will also always correctly indicate the weight of the mass of air aloft, both when it is at rest and when it is in rapid motion, accompanied by the important element of friction. Equal identity of pressure in both such cases is assumed, although no observations to justify the correctness of this assertion have been made. With the atmosphere in a state of perfect rest, setting aside just now the effects of heat and vapour, there will be an upward *normal* diminution of pressure, but with the same superincumbent mass of air no longer at rest, but attended with the dynamical element of motion in the rapid upper strata, will there not then be an upward *abnormal* diminution of pressure, due to the "lifting" of the air on the surface and its accumulation aloft? It is this point which was shown in the former paper, and is now here to be more fully explained. In both such cases, and under the same superincumbent mass of air, can the barometer, placed on the *surface*, possibly show the same amount of pressure? It is only by a series of barometers placed vertically above each other to a great height, and not very far apart, that the amount of pressure in both such cases will be found to be the same.

Mathematical meteorological investigations cannot be here introduced with perfect accuracy, and only to a small extent, where so much complexity, irregularity, and want of uniformity is to be

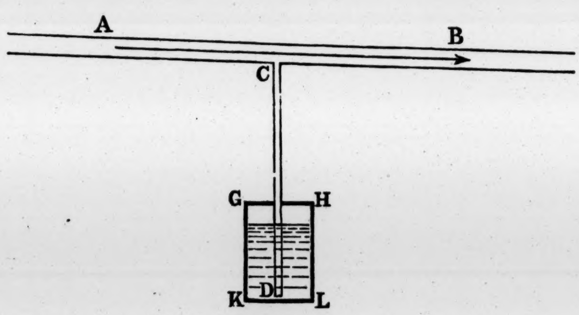
found, and where barometric observations are not always absolutely reliable, nor also are the gradients and isobars which depend upon them. In such an imperfect state of matters, exceptional cases must always be found, and these, if not disadvantageously too numerous, must consequently, as above remarked, be regarded as being a negative test or proof of the conclusions arrived at. The importance of barometric observations is however well known, but, as has been pointed out by the Astronomer Royal and others, a great mass of these is valueless and simply overwhelming, while comparatively few definite conclusions have as yet been arrived at. Hence explanatory theories must be produced to point out the particular direction in which such observations ought to be carried out. In such a subject as this, the greater the extent to which investigation takes place the greater will be the amount of difficulty and complexity, but such a discovery is only to be regarded as being a more accurate approach to ultimate reliable conclusions.

The object of this paper is to show, mainly in a mechanical point of view, why the fall of the barometer to a great extent is due to strong winds, setting aside at present the much smaller amount of fall produced by heat and vapour. In other words the point to be explained is,—why horizontal movement takes off vertical pressure. This fall, due to strong winds, is produced by a real *removal* of air and the amount to which it takes place will depend on the extent of the resisting surface over which the winds pass, and also on the amount of their source of supply, which is indicated so far by the steepness of the gradients. In a somewhat similar way, when the incline at the bottom of a river is very slight, the current will then move slowly, and will tend to deepen and accumulate, but when the incline is much steepened, the current will then increase in speed, removal will now take place, and it will consequently shallow out. Although the barometer thus falls for "removal" of air, it is intended to show that this fall is not entirely due to removal, but that it is also partly due to "lifting," which is an exhibition of fictitious pressure. The barometer has been described as being both a cause and an effect. An area of low pressure is a *cause* of the indraught of aerial currents, but owing to the peculiar mode in which they inflow to this low centre by rapid upper currents, a still further diminution of pressure will take place, as just above mentioned, and this

is to be regarded as being an *effect*. In another point of view, it may be here mentioned, that if a very swift wind blows over a convex surface, pressure will then be diminished, but if the convexity is that of the earth's surface, and the velocity that of actual winds, the effect will be far too small to be sensible.

These rapid upper currents and their effects, to which so much importance has been attached, do not consist merely of light rarefied upper aerial strata which can be possessed of little momentum. The mode in which they are constructed may be thus described. Their velocity begins to increase at only a few feet above the surface, as has been shown by observations; this increase goes on often to a great height in the atmosphere, much of it, however, is to be found in the more weighty and condensed mass of the air not much above the surface, where it must be accompanied by a powerful force due to its momentum. The weight of a cubic mile of air amounts to several millions of tons; where many such are in motion, their weight and their accompanying momentum will be sufficiently prodigious to produce the effects which have been pointed out.

From experiments made by Halley and Hawksbee, they came to the conclusion that horizontal movement took off vertical pressure, while Professor Leslie experimented to refute this.* A well-known experiment will illustrate this. If a current of water flows down an incline in the direction of the arrow AB, instead of falling down

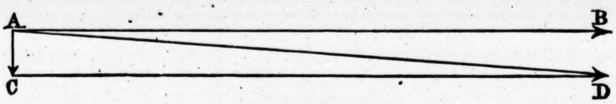


Diag. No. 1.

through the orifice at C, it passes over it and draws up or lifts through the small tube CD the water contained in the vessel GHKL. This is carried out at the expense of the momentum of the greater current, in which, in this way, an additional amount of water is *accumulated*. The gravity of the current as

* See "Trans. Roy. Soc. Edin." vol. xx. p. 377.

it passes over the orifice at C is undiminished; notwithstanding this, it does not here descend. Why it does not do so may be thus explained. Its gravity, which operates in a downward vertical direction AC, is here altered by its horizontal velocity,



Diag. No. 2.

AB in the direction of the component AD. Attraction to the earth's centre remains undiminished; but if in this way it is distributed over a greater extent of surface, on any point of it, it may then practically be regarded as being really diminished. The weight of the current passing over the orifice at C may therefore be regarded as operating in an altered direction. With an incalculable amount of velocity, gravity may be said totally to disappear. The distribution of pressure may be exemplified by a cannon ball which, if it falls directly downwards from the mouth of the gun, will then show its full weight when it comes in contact with the surface of the ground, but if it moves rapidly in a horizontal direction its weight may now be regarded as being distributed over an extent of surface, on any point of which it is there diminished practically. When skating slowly over thin ice, it gives way, but by passing rapidly over it, this may be done in safety. The explanation of this is, that the ice has not here time to give way; this is no doubt so far correct; but it must also be observed, that the weight of the skater, if at rest, is to be found in a vertical direction and is then undiminished, but when he moves it is then distributed over the surface of the ice and is in this way lessened. The greater the amount of velocity, the greater will be the practical diminution of pressure over a corresponding extent of surface.

Let a current of air move rapidly along the incline AB in the mode above shown. Let the vessel GHKL, which held water, now only contain air, air will in the same way be drawn up, *lifted*, and *accumulated aloft*, in the rapid motive current AB. If the vessel is enclosed on the top, the tube by which the air is drawn up from it will produce within it rarefaction and diminution of pressure, and only a slight accumulation aloft, as its source of supply is now entirely restricted. Upward abnormal diminution of pressure in

the atmosphere caused by the introduction of the element of dynamical motion is due to this accumulation of the air aloft, and is consequently accompanied by increase of pressure there, and by diminution of pressure on the surface. Let the arrow AB represent

Diag. No. 3.

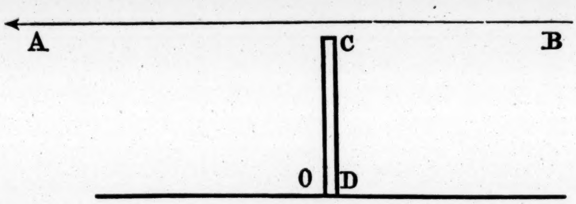
the strong upper current, and let the diminution in length of the arrows beneath it represent the diminution in the rate of their speed. As was shown in the diagram in the last paper* on this subject, these strong upper currents obtained much of their necessary source of supply by "lifting" it from the slower and more retarded surface currents beneath them. The direction in which this lifting takes place is shown by the small arrows inclined in the direction in which movement takes place. Accumulation is here indicated by the comparative closeness in the parallel position of the arrows, while the rarefaction and diminution of pressure on the surface, due to lifting, is indicated by their comparative wideness in the parallel position of the arrows there. It is only with a highly elastic fluid such as air, aided also by a certain amount of viscosity, and accompanied by horizontal surface retardation, that this alteration in the position of vertical pressure can take place. If the moving currents are non-elastic fluids, such as mercury, their rapidly moving upper strata will only cause a real diminution of pressure on the surface, but no increase of pressure or of accumulation aloft, because lifting cannot here take place. With a perfect fluid, also, no surface retardation will be found, and no difference in the speed of currents in so far as they are due to this cause. Hence here, as on a frictionless surface, "lifting" will not take place.

When a very rapid rise of the barometer takes place, as is frequently to be found in West Indian hurricanes, it may at least so far be accounted for in this way; when abnormal upward diminution of pressure is found due to accumulation aloft, as shown in the diagram No. 3, and when the motive force which produces it and

* Proc. Roy. Soc. Edin. 1876–77, p. 412.

holds it up in this position has come to a termination, a vertical rapid descent of the accumulation will of course take place to overcome the diminution of pressure on the surface, and in this way it will at least so far approach the form of upward normal diminution of pressure. A rapid fall of the barometer on the surface will also in a similar but in a reverse way take place, when accumulation begins to take place, with diminution of pressure on the surface. Upward *normal* diminution of pressure, which is here made use of as an exemplification of what takes place, is in all probability seldom or never to be found, as the atmosphere is rarely, if ever, in a state of perfect rest, nor is there any uniformity in the effects of heat and vapour. It is only in a mechanical point of view that it can assist in explanations.

When the wind, represented by the arrow AB, blows over the top of a wall CD, it will lift the air and diminish pressure on the lee side at



Diag. No. 4.

the point O, though only to a small amount, while the weight of the atmosphere may be said to be unaltered. This diminution of pressure is caused by the wall, which retards the velocity of the wind. Friction on the surface of the earth may be exemplified by a long series of such walls, which will produce diminution of pressure immediately above them. It is only on a very extensive surface of, say several hundred miles in length, with a corresponding width, that strong upper currents can produce lifting and diminution of pressure to its full extent; under such circumstances, the comparative height of these upper currents will not be great as compared with their length. Redfield has pointed out that depressions have often a height of only $\frac{1}{200}$th part of their width, while in other instances their height may be comparatively great in reference to their width, in which case little or no diminution of pressure will be found. The effect of such an extensive resisting surface is to produce retardation of the surface currents, along with an imperfect amount

of supply. If these are not found, "lifting" will not take place. The importance of the difference in the comparative height and length of the currents, and of the depressions, in a mechanical point of view, was taken advantage of in the last paper* to show how depressions opened out in front, and by so doing moved forward.

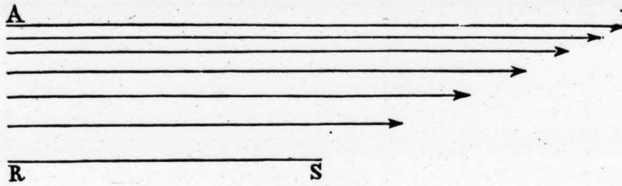
An exemplification of the effect of an extensive surface which produces low pressure may be found in the southern hemisphere below lat. 40°, where what are called the "roaring forties" are to be found, in often interminable gales from a westerly direction, and with little intermission, and extend over a vast portion of the globe. The Rev. S. J. Perry, in his voyage there, found the average height of the barometer there to be in November, 29·658°; in December, 29·462°; in January, 29.406°; February, 29.610°. This may therefore be accounted for by removal and lifting. In other countries, where calms and light winds prevail,—where strong winds blow only for a short time over a small extent of surface, as in the Mediterranean, no such low pressure is to be found. In explanations attached to the barometer, to show the effects of its rise and fall, calms are predicted when the mercury is high, as a general rule. Local exemplifications of lifting from the bottom of a valley are to be found in the Fohn in Switzerland, where the wind passes rapidly over their summits, and are also to be found on the lee side of precipices.

In the diagram No. 1, where the current of air AB lifts up the air from the vessel GHKL, which is now enclosed on the top, and has now its source of supply arrested, it is then that rarefaction and diminution of pressure takes place to the full extent. This may also illustrate the effect of an extensive resisting surface in arresting the source of supply to its surface currents and causing their retardation. In a former paper† it was stated that, in weather charts, the constant rise and fall of the barometer, which is there reported, *is to a large extent simply due to the passage of air over a resisting surface; on a frictionless surface these mechanical effects would be entirely removed.*

There is an important difference in the mode in which Equatorial as compared with Polar winds, inflow to a low centre. Let these

* Proc. Roy. Soc. Edin. 1877–78, p. 572.
† Proc. Roy. Soc. Edin. 1876–77, p. 414.

be exemplified by S.W. winds, which cause a fall in the barometer, while N.E. winds create a rise. South-west are accompanied by rapid upper currents, and let these be represented in the diagram No. 5 by the arrow AB, while the less rapid currents beneath are exhibited by the shorter arrows. RS is the surface of the ground.



Diag. No. 5.

Let the narrowing in the parallel position of the upper arrows represent accumulation aloft, and their widening below represent rarefaction and diminution of pressure. In this way, and also owing to removal of air, the fall of the barometer with these winds may be shown. North-east winds are not accompanied by rapid upper currents, which move somewhere about the same rate of speed as those on the surface. For the sake of illustration, let it be supposed that they move even more slowly, and let them be indicated by the shorter arrows AB above, while the more rapid surface currents passing over the surface RS are shown by the longer arrows beneath. In this case

Diag. No. 6.

surface retardation, in so far as it is indicated by the difference betwixt the comparative speed of the currents below and above, will not here be found, although, of course, it really takes place. Accumulation aloft cannot here be found; it will now take place on the surface, as is shown in this diagram by the closeness of the parallel position of the arrows there. This tendency to condensation, which was also to be found in the former instance, was there removed by the rapid upper currents, which here are not to be found. With these N.E. winds, therefore, as removing and lifting does not take

place, they are accompanied by a rise of the barometer. The mode in which these N.E. surface winds are enabled to overcome the effect of friction, and to accumulate on the surface, may be thus explained. They are cold and dense, and they enter underneath a milder atmosphere in the form of a wedge and raise it above them. To enable them to do this they must have a copious source of supply from an area of high pressure, and they are also aided generally by descending currents, which possess a great amount of potential energy.

As is well-known by seamen, these surface N.E. winds appear with a remarkable amount of suddenness and violence, and the disasters which accompany them have been often recorded. South-west gales which blow aloft approach much more slowly, and, as this approach is first exhibited aloft, they can be predicted with much certainty.

In the last paper just alluded to it was mentioned that the range of the thermometer is equally great both above and below its mean. But with the barometer, the extent of its range above the mean is not more than one-half of that which takes place when it is below it. When it is below the mean, Equatorial winds generally prevail, such as those S.W. just alluded to, which are accompanied by removal and lifting. When above the mean, Polar winds and calms prevail, which are not accompanied by removal and lifting. Hence, as a general rule, Equatorial winds exhibit an amount of fictitious pressure, while Polar winds show more nearly, real or statical pressure, which, however, may possibly be so much in excess. Much important information as to the mobility of the upper aerial strata may be shown by the experiments made by Professor Tyndall at Chamouni, and at the summit of Mount Blanc.

From observations made by the late Mr Johnson, director of the Oxford University Observatory, it was found that, at a height of 110 feet from the ground, the velocity of the wind was found to be $2\frac{1}{4}$ times that indicated by an instrument at 22 feet above the soil. This velocity, of course, increases with the elevation, and to the extent of five or six fold, as shown by Glaisher. In the address of the President, H. S. Eaton, on 21st February 1877, he alludes to the ascent of a balloon from Paris. At an elevation of 6560 feet, a violent wind was encountered, and on

reaching a point 187 miles north of Christiania, and nearly 1000 miles from Paris in a direct line, the balloon must have sailed at the rate of at least 66 miles an hour, while nowhere did the extreme speed of the wind registered at any observatory at all approach the speed of the balloon. When the stratum of clouds overhead is of sufficient depth, and when the difference in the velocity of their different strata is sufficiently great, a columnar inclination of the clouds in the direction in which they move will be observed. This will illustrate the inclination of the columns of air which represent the increasing upward velocity of the winds, and is so often referred to.

Over the ocean, as seamen are well aware, sea birds, when strong winds prevail, attempt to fly only on the surface, where their velocity is retarded, while above this they are unable to move against them.

To ascertain the amount of diminished or fictitious pressure which is due to lifting, the real weight of the same mass of atmosphere must be ascertained both when it is at rest and when it is in motion. The results of such an observation, if made by a series of barometers placed vertically above each other to a great height, and not very far apart, will, in each case, exhibit an equal amount of pressure, and when the atmosphere is at rest, the barometer on the surface will then alone show its true weight, but when it is in motion, the barometer on the surface will then indicate diminished or fictitious pressure, because the air is then so far lifted and rarefied immediately above the surface, and is accumulated aloft with increase of pressure there. The result of this, as shown, is an upward abnormal diminution of pressure. The barometer always shows the real pressure of the air in contact with its cistern, which it does in this latter instance, but it does not here show the weight of the superincumbent air, while in the former case it showed both accurately. In this way, and also for other reasons, it does not indicate correctly the height of mountains, nor can observations made at some height and then reduced to sea-level be at all dependable.

Observations with a series of barometers as thus just above suggested, will be best carried out in a wide open atmosphere over the sea, and not in contact with the slopes of a lofty mountain, which,

for many reasons, must necessarily derange the observations. As no such direct observations can be made at all, results can only be arrived at from those which are not absolutely definite and conclusive. Aided by theory, some of these may be here suggested.

Observations were made by Captain James in his cottage at Granton during the prevalence of strong winds.* When this took place in the form of violent gusts, the instrument placed in one of the rooms, where, of course, it was so far confined, showed then a considerable lowering of pressure, while that placed outside remained comparatively unaltered. Could this cottage have been so arranged or constructed as to move forward at a uniform rate of speed with the gusts, pressure inside would not then at all be reduced, because no local confinement or retardation of the air would then take place; its amount would then be the same as that shown by the instrument outside.

Experiments were made by the writer at Craigleith Quarry, near Edinburgh, with a barometer placed at the top and at the bottom: the depth of the quarry, as compared with its width, is considerable. The remarkable difference at these spots was this, that while the height of the mercury, as observed at the upper part of the quarry, remained uniform, or nearly so, during strong gusts; at the bottom, its oscillations were very great, with much occasional diminution of pressure, which then took place when the gusts passed rapidly over the upper surface, to which the air was drawn up from the bottom; "lifting" and accumulation aloft are thus exemplified. At the bottom, where the air was confined, retardation took place. Had there been no such confinement—had supply there been equally copious as on the surface, no such oscillations would have taken place. This is also illustrated by a waterspout, as shown in the first paper on this subject in 1875.

Observations to throw light upon the subject in question may be made in the following manner: When a strong wind blows over the sea, let there be placed at anchor in the direction in which it blows a line of vessels with instruments placed on deck to show pressure. The wind passing over them may then be represented as moving in inclined columns, in which case the barometer does not indicate the real mass of the air aloft. Let another vessel now move forward in

* See "Trans. Roy. Soc. Edin." vol. xx. p. 377.

the direction and at the same rate of speed as that of the wind, a calm will now prevail over its deck, and the columns above it may then be regarded as being vertical, and indicative of the real weight of the air aloft; when it passes close alongside of those at anchor, a difference of pressure will be found on each, although the mass of air aloft is the same. For various reasons, however, the real amount of difference here will not in this way be correctly ascertained, and it will not be great. If a calm prevails over the vessels at anchor they will then show the real weight aloft. The moving vessel will now produce and encounter a force of wind equal to her rate of speed, and will not now show real weight aloft.

Vessels crossing the Atlantic against the strong prevailing west winds, will increase their force in proportion to the rate at which they sail against them. They must, therefore, indicate a difference of pressure when passing those vessels returning with the winds in their favour. Its amount will not be great, because the extent of the resisting surface which is represented by their decks is insufficient to produce retardation of horizontal and lateral supply. If, however, the instruments are placed in some enclosure, as was seen in the cottage, some amount of difference of pressure will then be shown.

For want of space here, and owing to the extreme difficulty of the subject, it cannot here be fully explained, but it may be stated that the conclusion has been arrived at, that as a general rule, the barometer in the Tropics, with, of course, exceptional cases, more nearly shows the real weight of the atmosphere than it does in more northerly latitudes. In countries of very different descriptions of structure and climate, this will probably be found to be the case, and also over the land and the sea.

The isobars, which are constructed on the supposition that the barometer always shows the real weight of the air, cannot be accurate. In the different segments which surround an area of low pressure, they will require a difference in the amount of their correction.* In the same way, and for other reasons also, gradients which are figuratively equal, as is well known, do not exhibit the same amount of incline, or the same amount of inflow of the winds. Correction here is evidently also necessary.—*May* 1878.

* See "Proc. Roy. Soc. Edin." 1874–75, p. 618.

3. On Some New Bases of the Leucoline Series. Part II. By Mr G. Carr Robinson and Mr W. L. Goodwin.

4. On a Calculus of Relationship. By Alexander Macfarlane, M.A., D.Sc., F.R.S.E.

1. De Morgan read a paper on the "Logic of Relations" before the Cambridge Philosophical Society, and the paper is printed in their Transactions. He attempts to deal not only with the idea of *relationship*, but with the idea of *relation* in general. As he does not deal with exact ideas, he cannot give any exact results.

2. Among the writings of Leslie Ellis there are printed some notes on Boole's "Laws of Thought," and there he refers to the idea of relation. He makes the important remark:—"It seems to me that the mind passes from idea to idea in accordance with various principles of suggestion, and that, in correspondence with the different classes of such principles of suggestion, we ought to recognise different branches of the general theory of inference." But he proceeds to discuss equations expressing any kind of relation, thus neglecting his own principle of making a special investigation for each really different kind of idea.

3. What I have attempted to do is to devise a complete analytical notation for what can be represented graphically by means of a genealogical tree, to consider how data about relationships should be expressed, and to point out rules for manipulating these data.

4. The distinction between the *relationship* and the *persons between whom the relationship exists*, can be represented by means of small letters in contradistinction to large letters—*e.g.*,

$$sA = B + C + D$$

The sons of A are B, and C, and D.

5. The symbol s has a definite arithmetical value, which is an integer. It is a multiplier, or operating symbol, which changes A into B and C and D.

6. To express any relationship whatever, we require only four fundamental symbols expressing the four fundamental relationships (1) of a father to his sons, (2) of a father to his daughters, (3) of a

mother to her sons, and (4) of a mother to her daughters. These may be denoted respectively by

$$s, \quad d, \quad \sigma, \quad \delta.$$

7. *Superior indices* and *inferior indices.* In an investigation we may require to consider several different s relationships; these are best distinguished by means of superior indices, *e.g.*,

$$s^1, \quad s^2, \quad s^3.$$

We also require to consider one of the s's, say the nth; this is properly denoted by s_n.

8. The sign $=$.

Let

$$sA = B + C + D.$$

This equation asserts that the sons of A comprise B, C, and D exactly, neither more nor fewer.

The equation $$sA = \sigma B$$

denotes that the sons of the man A are identical with the sons of the woman B. The truth of the equation involves

$$\bar{s} = \bar{\sigma},$$

where the bar denotes that the arithmetical value of the symbol is taken. What $=$ denotes is *identity* of persons—not necessarily identity of relationships. Equations which express the latter idea may be called identities.

9. The sign $+$ has its ordinary meaning. For example—

$$sA = \sigma^1 B + \sigma^2 C$$

The sons of the man A are identical with the sons of the woman B, together with the sons of the woman C.

10. The law $$s + d = d + s.$$

It is obvious that the formal law

$$(s + d)A = (d + s)A,$$

which means—

The sons together with the daughters of A are identical with the daughters together with the sons of A—

is true whoever A be.

11. The sign $\times$.

$$s^1_m \; s^2_n \; A$$

denotes the mth son of the nth son of the man A. The operators

s^1 and s^2 are similar as regards their nature, but are different individually. Consequently their arithmetical values may be different.

12. In this branch of analysis, order is essential. The operator s^2 is prior to s^1. Hence the commutative law does not apply to symbols connected by $\times$.

$$s^1{}_m s^2{}_n \text{ is not } = s^2{}_n s^1{}_m.$$

In this respect the branch of analysis which investigates relationship stands in contrast to the branch of analysis which investigates quality. For in the latter

$$xy = yx.$$

At the same time it agrees with the Quaternionic analysis, for in it

$$pq = qp$$

is not true in general. (Tait's "Quaternions," p. 37.)

13. I may here quote a few sentences from a paper by the late Professor Clifford, which throw light on this subject—

"There are two sides to the notion of a product. When we say $2 \times 3 = 6$, we may regard the product 6 as a number derived from the numbers 2 and 3, by a process in which they play similar parts; or we may regard it as derived from the number 3 by the operation of doubling. In the former view, 2 and 3 are both numbers; in the latter view 3 is a number but 2 is an operator, and the two factors play very distinct parts." The product of two *quality* symbols is of the former kind; the product of two *relationship* symbols is of the latter kind.

14. $$s_m A = B$$

asserts that B is the *m*th son of the man A.

$$A = \frac{1}{s_m} B$$

asserts that A is the father of the man B, and that B is the *m*th son. Thus,

$$\frac{1}{s_m}$$

does not only denote "father of a male," but introduces the proper number to individualise the relationship.

15. Suppose that we have given the two equations

$$s_m A = B, \quad \text{and} \quad s_n A = C,$$

then
$$B = s_m \frac{1}{s_n} C,$$

and
$$C = s_n \frac{1}{s_m} B.$$

The expression $s_m \frac{1}{s_n}$ denotes the relationship of sons of the same father.

If $m = n$, then $B = C$.

Thus the general analytical expression for brother includes *oneself.*

16. De Morgan remarks on the difficulty commonly experienced by persons of putting together two (not to say more than two) conditions about relationship, that is, of deducing the conclusion from two given data which really afford a conclusion. He was accustomed to propound the following story, among others, as a test:—An abbess observed that an elderly nun was often visited by a young gentleman, and asked what relation he was. "A very near relation," answered the nun; "his mother was my mother's only child."

Let G denote the gentleman, and N the nun. Then the conditions given are—

$$\frac{1}{\sigma} G = \delta \frac{1}{\delta} N, \quad \text{and } \bar{\delta} = 1.$$

Since $\bar{\delta} = 1$, $\delta \frac{1}{\delta} = 1$ (Art 15),

$$\therefore \quad \frac{1}{\sigma} G = N$$

$$\text{or} \quad G = \sigma N.$$

That is, the gentleman was the son of the nun.

When the visitor is not said to be young, the problem presents still greater difficulty to the ordinary intelligence.

17. Suppose $$s_2 s_4 A = s_2 \frac{1}{s_1} \frac{1}{d_1} M,$$

that is, the second son of the fourth son of A is identical with the second son of the father of a man his first son who was the father of a woman his first daughter M.

Then $$\frac{1}{s_2}\, s_2\, s_4\, \mathrm{A} = \frac{1}{s_1}\, \frac{1}{d_1}\, \mathrm{M},$$

and $$\frac{1}{s_2}\, s_2 = 1 \qquad \text{(Art. 24)},$$

$$\therefore \quad s_4\, \mathrm{A} = \frac{1}{s_1}\, \frac{1}{d_1}\, \mathrm{M}. \qquad (1)$$

Also $$s_1\, s_4\, \mathrm{A} = \frac{1}{d_1}\, \mathrm{M}; \qquad (2)$$

$$d_1\, s_1\, s_4\, \mathrm{A} = \mathrm{M}; \qquad (3)$$

and $$\mathrm{A} = \frac{1}{s_4}\, \frac{1}{s_1}\, \frac{1}{d_1} \mathrm{M} \qquad (4)$$

Hence the rule for changing a relationship function from one side of an equation to the other is,

Invert each symbol of the function which is to be transposed, reverse the order of the symbols, and prefix before the function which is on the other side.

18. As an example of the value of the notation of this calculus, considered merely as a shorthand, I may express the relationship between Queen Victoria and Mary Queen of Scots—

$$\mathrm{V} = d\, s_4\, s_1\, s_1\, s_1\, \sigma_1\, \delta_a\, d_b\, \sigma\, \mathrm{M}.$$

Here there is no need in two cases to put a suffix, because $\bar{d} = 1$ and $\bar{\sigma} = 1$.

This relationship can be expressed in nine other forms, each equivalent to the above form, by taking over d, ds_4, ds_4s_1, &c., to the other side, after having transformed the expression in accordance with the Rule of Art. 17.

In two cases I have used a and b because I am uncertain of the actual numbers.

19. The signs $>$ and $<$.

$$\mathrm{B} + \mathrm{C} + \mathrm{D} = s\mathrm{A}$$

asserts that B, C, and D, and no others, were sons of A.

$$\mathrm{B} + \mathrm{C} < s\mathrm{A}$$

asserts that B and C, at least, were sons of A.

Thus the sign $<$ means *are included in*, as in the analysis of quality.

This is, of course, an important point. Leslie Ellis expresses

Shem was a son of Noah

by

$$S = sN;$$

but, so far as I have yet studied the matter, I am inclined to hold that s must be considered as in general a plural symbol, and that

$$S = sN$$

asserts implicitly that Shem was the only son of Noah. The truth

Shem was a son of Noah

is properly expressed by

$$S < sN;$$

but the truth

Shem was the eldest son of Noah,

by

$$S = s_1N.$$

20. Let f denote *father of* and m denote *mother of.* Then

$$f=\frac{1}{s+d} \quad \text{and} \quad m=\frac{1}{\sigma+\delta}.$$

21. *To find expressions for one's ancestors of the nth generation back.*

$$f + m$$
$$f + m.$$

Multiply together

$$\text{then } ff + mf + fm + mm.$$

These are the expressions for one's grandparents.

Multiply again by $f + m$,

then $fff + mff + fmf + mmf + ffm + mfm + fmm + mmm.$

These are the expressions for one's great-grandparents.

And so on.

The maximum number of ancestors of the nth generation back which a person can have is 2^n, and the minimum number according to the Laws of Consanguinity is 4.

22. According to the above, the relation of great-grandmother may denote any one of the four different relations—

$$mff, \quad mmf, \quad mfm, \quad mmm;$$

and, taking into account the gender of the great-grandchild, there will be eight different relationships.

23. The notation I have framed is of great use in showing the ambiguities of the common terms of relationship. Thus uncle may may mean any one of eight things, or a combination of these. For example—

Uncle and Nephew.

$$\left\{\begin{matrix} s_1\frac{1}{s_4}\ \frac{1}{s_2} \\ \sigma_1\frac{1}{\sigma_4}\ \frac{1}{s_2} \end{matrix}\right. \qquad \left\{\begin{matrix} s_1\frac{1}{d_4}\ \frac{1}{\sigma_2} \\ \sigma_1\frac{1}{\delta_4}\ \frac{1}{\sigma_2} \end{matrix}\right.$$

Uncle and Niece.

$$\left\{\begin{matrix} s_1\frac{1}{s_4}\ \frac{1}{d_2} \\ \sigma_1\frac{1}{\sigma_4}\ \frac{1}{d_2} \end{matrix}\right. \qquad \left\{\begin{matrix} s_1\frac{1}{d_4}\ \frac{1}{\delta_2} \\ \sigma_1\frac{1}{\delta_4}\ \frac{1}{\delta_2} \end{matrix}\right.$$

The relationships bracketed together generally coexist.

24. To prove that

$$\frac{1}{s}s \text{ always } = 1\,.$$

Let $$A = \frac{1}{s}sB,$$

then $$sA = sB.$$

But that is morally, if not physiologically, impossible unless $A = B$,

$$\therefore \qquad \frac{1}{s}s = 1\,.$$

Similarly $$\frac{1}{\sigma}\sigma = 1\,.$$

Observation.—Neither $\frac{1}{s}\sigma$ nor $\frac{1}{\sigma}s$ can be equal to 1.

25. To express that

A is the brother of the brother of B.

The expressions for brother are—

half-brother $s\frac{1}{s}$, $\quad s\frac{1}{d}$, $\quad \sigma\frac{1}{\sigma}$, $\quad \sigma\frac{1}{\delta}$;

and full brother $$\left\{\begin{matrix} s\,\frac{1}{s} \\ \sigma\,\frac{1}{\sigma} \end{matrix}\right\}, \qquad \left\{\begin{matrix} s\,\frac{1}{d} \\ \sigma\,\frac{1}{\delta} \end{matrix}\right\}.$$

Hence brother of brother is denoted by

(1) $$s\frac{1}{s}\ s\frac{1}{s} = s\frac{1}{s} \qquad \text{(Art. 24)}$$

(2) $$s\frac{1}{s}\ s\frac{1}{d} = s\frac{1}{d} \qquad \text{"}$$

(3) $s\frac{1}{s}\ \sigma\frac{1}{\sigma}$

(4) $s\frac{1}{s}\ \sigma\frac{1}{\delta}$

(5) $\sigma\frac{1}{\sigma}\ s\frac{1}{s}$

(6) $\sigma\frac{1}{\sigma}\ s\frac{1}{d}$

(7) $\sigma\frac{1}{\sigma}\ \sigma\frac{1}{\sigma} = \sigma\frac{1}{\sigma}$ (Art. 24)

(8) $\sigma\frac{1}{\sigma}\ \sigma\frac{1}{\delta} = \sigma\frac{1}{\delta}$ ”

Subscript letters are to be understood. If in the case of 1 or 7 the subscript letters are the same, then

$$A = B.$$

26. To prove that $$s\frac{1}{\sigma} = 0.$$

Let $$A = s\frac{1}{\sigma}B;$$

that is, let A be the son of a male who is the mother of the male B.

But this is impossible in the case of the human species, where sex is monœcious. Hence A is imaginary; and therefore

$$0 = s\frac{1}{\sigma}B,$$

whoever B is.

27. The different permutations of the four fundamental symbols used directly and inversely may be exhibited in a table. I append one-fourth part of the complete table, marking the expressions which are impossible or which denote coincidence.

ss	$s\sigma$	$sd = 0$	$s\delta = 0$
$s\frac{1}{s}$	$s\frac{1}{\sigma} = 0$	$s\frac{1}{d}$	$s\frac{1}{\delta} = 0$
$\frac{1}{s}s = 1$	$\frac{1}{s}\sigma$	$\frac{1}{s}d = 0$	$\frac{1}{s}\delta = 0$
$\frac{1}{s}\ \frac{1}{s}$	$\frac{1}{s}\ \frac{1}{\sigma} = 0$	$\frac{1}{s}\ \frac{1}{d}$	$\frac{1}{s}\ \frac{1}{\delta} = 0$

28. The Marriage with a Deceased Wife's Sister Bill would make the following among other equations possible:—

$$s_a = \sigma^2{}_b d_c \frac{1}{d_d} \frac{1}{\sigma^1{}_e} s_f .$$

29. As the analysis of relationship is important not only in itself, but also as throwing light upon the nature of operators in Mathematics, I propose to continue the investigation, and to bring the results before the Society at a future meeting.

Monday, 2d June 1879.

SIR C. WYVILLE THOMSON, Vice-President, in the Chair.

The following Communications were read:—

1. On the Carboniferous Volcanic Rocks of the Basin of the Firth of Forth: their Structure in the Field and under the Microscope. Second Paper. By Professor Geikie.

2. Additional Observations on the Fungus Disease affecting Salmon and other Fish. By A. B. Stirling, Assistant Curator of the Anatomical Museum of the University of Edinburgh.

In my former paper, read before the Society in June 1878,* I gave an account of observations which I had made on the fungus disease affecting salmon, and described the character of the fungus, which I referred to *Saprolegnia ferax.*

In the present communication I propose to relate additional observations, and to discuss the theories which have been advanced by different writers in explanation of the cause of the disease. Four theories have been advocated, namely—pollution of rivers, overcrowding, absence of frost, diseased kelts and addled ova.

In reference to the theory that pollution is the cause of the

* See *Proceedings* of that date.

fungus disease of salmon and other fish in the rivers at present affected by it, I think it is only necessary to relate the fact, that diseased fish are found in those rivers many miles above all sources of pollution, to prove that it cannot have originated from that cause. In the Eden River, for twelve miles above Carlisle, a district in which there is no big town or other sources of pollution, the fungus disease has been found as deadly as below Carlisle after the sewage of the city has entered the river. In the Tweed also, both trout and greyling, which are non-migratory fish, have been found affected with fungus where no source of pollution is known to exist; for I have obtained trout from near Broughton, and greyling from near Stobo, both of which are from seven to ten miles above Peebles, the town highest up the Tweed. Mr Buckland also, in his Seventeenth Report on the Salmon Fisheries, England and Wales, 1878, states "that we must look to other circumstances in order to diagnose the origin of the mysterious disease."

The theory of overstocking as the cause of the disease has been advocated by Mr Buckland in the same report. He considers that "owing to the absence of freshes (spates) in a river, the spawned fish do not find their way to the sea, so that they accumulate in the pools in which the disease breaks out amongst them, as gaol-fever affected the crowded prisons in former times."

In May 1874 the Tweed Commissioners constructed a small pond for experimental purposes, which measured 36 feet by 16 feet, on the side of a small stream called Carham Burn, from which a run of water was supplied to the pond by a drain pipe. On 7th May 1874, 130 sea-trout smolts, the average length of each being 8 inches, were taken from the Tweed and placed in this pond. After an interval of two years they were specially examined, weighed, and measured on the 25th May 1876. Seventy fish were found in the pond, the average length of each was $12\frac{1}{2}$ inches; they were now in the whitling stage, and in fine condition. After another interval of two years there was another examination, when they were weighed and measured on the 23d May 1878, when sixty-six sea-trout, of the average length of $14\frac{3}{4}$ inches, were found in the pond.

In the interval between the examinations, and probably in the season 1876–77, the fish had spawned in the pond, and a numerous

progeny of parr and orange-fins were found along with them, all of the fish being in fine condition—the kelts being well mended. On 25th July of the same year they were, on the occasion of the pond being cleaned, again weighed and measured; they now averaged 15 inches each. They were again returned to the pond, and retained there till the 22d of May 1879, when thirty of them were marked with silver wires and returned to their native Tweed.

It will thus be seen that sixty-six large fish, whose united length is 80 feet, along with multitudes of parr and orange-fins, were cribbed, cabined, and confined for five years in a pond no larger than an ordinary dining-room, and remained in health during that period without exhibiting any signs of fungus disease, and this although the pond is situated within a few hundred yards of the Tweed—an affected river.

There can be no comparison, I submit, between a salmon-pool in a river—where the full current of the stream flowing through the pool provides for a constant change of water—with a confined pond fed only by a small pipe of water and crowded with fish; and yet, in the latter, no disease or death, other than that of kelts after spawning, has ever been detected.*

* Since this reference to the Carham pond fish was read to the Society, it has been stated by Inspector Johnston of the Berwickshire Police that several fish had been found dead in the pond, which, in his opinion, had died of fungus disease. Those deaths, of which there can be no doubt, took place between 11th February and 3d May 1879, embracing a period of eighty-two days, during which five fish had been found dead in the pond by Mrs Robson, the gamekeeper's wife, who fed them. These fish were shown to Inspector Johnston, who apparently paid official visits to the pond, and from the appearance of the fish he concluded they had died of fungus disease. I do not accept Mr Johnston's opinion on this point. He was well aware that I was engaged in a scientific investigation of the disease; indeed he had, by order of Mr List, chief-constable, caught in the Tweed and forwarded to me several salmon to aid me in my research. It is singular then, that, knowing the interest I took in the pond fish, he was silent, and did not at the time report upon the disease, which, according to his version, had existed in the pond for eighty-two days, a period of sufficient length for the fungus to have destroyed the fish, both root and branch; also, according to his own statement, no one saw the dead fish, with the exception of himself and Mrs Robson, and probably Mr Robson, the gamekeeper; and, consequently, there is no scientific evidence that the cause of death was *Saprolegnia ferax;* and, to quote the words used by Mr List in a letter to me of 21st June, "if *Saprolegnia ferax* had been in the pond, it must have been seen on the fish on the 22d May, when we saw every one of them." Taking those facts into consideration, I adhere to my statement that

The theory of absence of frost is also advocated by Mr Buckland, on the ground that the frost kills the spores of the fungus, and prevents them from germinating.

Now, if this were the case, there ought to have been no disease during the past winter, as the severe and long-continued frost should have killed the spores. But we know that the disease has been of a most virulent character in the Eden, Tweed, and other affected rivers. But, further, I may add certain definite facts which show that the disease may spread even where a river is coated with ice.

On 5th February I received from J. Dunne, Esq., chief-constable of Cumberland and Westmoreland, four salmon which were taken alive from the river Caldew, and, along with them, a report by Inspector John Nicholson, who observed them for a period of nineteen days. Annexed is a copy of Inspector Nicholson's report.

"Constabulary Station,
"Eden Town, *4th February* 1879.

"Sir,—I beg most respectfully to inform you that on the 16th of last month five salmon were seen by me in a pool in the river Caldew, at Holme Head Bridge, one of which had a small white mark on the end of its nose, and which I thought showed symptoms

the case of the Carham pond fish fully proves that overcrowding is not the cause of fungus disease.

On the other side of the question—The pond-fish had been at least ten times specially examined during the five years they had been detained in it. By invitation of the chairman, I was present on two of those occasions, along with members of the experimental committee, Mr List the conductor of the experiment, a number of other gentlemen and practical fishermen, and it was a matter of surprise to all present that the fish were found in such fine condition.

At the final examination, which took place on 22d May 1879, I was prevented from being present, but arrangements were made that if any fish were found bearing marks of the disease they were to be transmitted to me. On the following day Mr List wrote to me that the "fish were in splendid condition for kelts, not the slightest sign of disease on any one of them."

It is well known among taxmen, practical fishermen, bailiffs, and anglers, that it is usual to find dead and dying salmon and sea-trout in rivers every season after they have spawned. This kind of mortality has been observed and written about for upwards of two hundred years. Isaac Walton mentions this as well known in his time, and there is no reason why the Carham détenus should be an exception to this rule, seeing they had spawned twice or thrice during their detention.

of fungoid disease. I removed other two salmon on the 19th of the same month from the mill-dam at Holme Head, and put them into the same pool for safety (they having been left nearly dry), making a total of seven salmon. On the following day I noticed a second marked on the dorsal fin. Since the last mentioned date I have not been able to see them distinctly, in consequence of the pool being frozen over with ice, until yesterday. I noticed three salmon affected out of the seven, and in a much worse condition—being all marked from head to tail; and this morning, on again examining them, I found the fourth slightly affected, making now only three out of the seven clear of the supposed disease.—I am, Sir, your most obedient Servant,

"JOHN NICHOLSON, *Inspector.*

"To Mr Superintendent SEMPILL,
"County Constabulary, Carlisle."

Each of the salmon mentioned in Nicholson's report had a label attached to it, stating when it was free of fungus, and when first observed to be affected, as follows:—

No. 1. A male kelt, 8 lbs.—"Observed slightly affected on 16th January."

No. 2. A large male, 30 lbs.—"Was free of fungus on the 16th January, and was seen to be slightly affected on the 20th January."

No. 3. A female, 14 lbs.—"Was free of fungus on 20th January, and was observed to be affected on the 2d February."

No. 4. A male kelt, 9 lbs.—"Was free of fungus on 2d February, and was observed to be affected with fungus on the 3d (or following day."

All those salmon were carefully examined—both anatomically and also microscopically. They were found to be affected with *Saprolegnia ferax* in various degrees of intensity over the whole body. The viscera and organs of generation were perfectly normal, and a number of valuable preparations have been added to the Museum which were prepared from them.

Inspector Nicholson's observations are very valuable, showing not only the sudden attack and rapid growth of the fungus upon the fish, but also that frost and ice have no effect in either checking or destroying the growth and spreading of the plant, as has been stated by Mr Buckland. The salmon noticed by Inspector Nicholson to

be free of disease on 20th January was a female, and was frozen over for twelve days—from 20th January to 2d February—during which period she had been attacked by the fungus, which had spread over her from head to tail. It is also worthy of remark that this fish had spawned while under the ice. Some of the ripe ova were found loose in the abdomen when I opened her for examination, and from the fact that one of the males frozen over along with her was in a condition to impregnate the ova, thousands of them may have been fertilised.

The fourth theory, that the kelts are diseased, and in consequence are first attacked by the fungus, and communicate it to the clean fish, I conceive to be no better founded than the theories of pollution, overcrowding, and absence of frost. In support of this opinion I quote from Mr Buckland's report, page 11, a statement by Inspector John Nicholson of the Eden district, in which he says—"That the total number of fish buried by the police since the 1st of March last is 1451. Between Armathwaite and Sandsfield there were buried 1271 salmon, 40 brandlings or parr, and 140 fresh water trout (*Salmo fario*), and in tidal waters of the river 100 salmon. The greater part of the 1271 above mentioned salmon were clean fish, having every appearance of having died of the disease so prevalent in the Eden at the time; about 50 were found at the river side in a dying state, which were killed and buried. About 200 were unclean salmon or kelts, which showed no symptoms of the disease; the brandlings and trout were all diseased." We have in this report evidence, and that on a large scale, that of the salmon buried by the police in the Carlisle district about 1000 affected with fungus disease were clean fish; the 200 kelts were not affected by the disease. Again, since I began to investigate the fungus disease, I have received, either from the Tweed or the rivers draining into the Solway, 16 salmon, 9 of which were clean fish. The addled ova suggestion is scarcely worthy of notice. There is no evidence that a salmon redd has ever been seen in any river in a state of fungoid growth, or that the fungus, if so grown, is the *Saprolegnia ferax*. Further, there is no evidence that the fungus which grows upon the carcases of dead kelts, which hitherto have been allowed to rot in the river, is the *Saprolegnia ferax*. The statement that this form of disease has been known in the Tweed for fifty years,

has, so far as I know, not been supported by scientific evidence, and rests mainly on the recollections of old anglers and fishermen.

I shall now proceed to relate observations on the disease as it has shown itself upon the salmon and other fish of the river Tweed.

On 12th April 1879, I received from G. H. List, Esq., chief-constable of Haddington and Berwickshire, three salmon, which were taken alive from the Tweed on 11th April. They were captured at Cornhill boat fishery, near Coldstream. All the fish were extensively affected with fungus on all parts of their bodies and fins.

The fungus is identical with that found upon the salmon and other fish of the Solway rivers described by me in 1878.

No. 1, a female salmon.—This fish was in the act of spawning when captured; complete dehiscence of the ovaries had taken place, and the greater part of the ova were shed, about six ounces, by measure, being retained in the cavity of the abdomen. The germinal membranes of the ovaries were plentifully supplied with germs for the following season.

The condition of this fish as a spawning baggit was very good; the skin, where not covered with fungus, was clear and silvery; the gills were high coloured and free from parasites of any kind; all the viscera were healthy, and a fair amount of fat adhered to the stomach and pyloric cæca. Blood taken from the heart, liver, spleen, and kidneys was carefully examined under the microscope, and was found to be perfectly normal. The lower part of the intestine was filled with a semi-transparent mucus of a pale rose colour, in which bacteria were very numerous. Two tape-worms of large size filled a considerable portion of the intestine with their plicated folds.

This salmon had over a dozen large patches of fungus adhering to it; one of them was 4 inches long by 3 inches broad, and was felted to one-fourth of an inch in thickness in the centre, forming a limpet-like crust of a slatey-grey colour. On careful removal of those patches of fungus, in most instances only a discoloured mark corresponding to the patch was seen adhering to the outer surface of the scales, which were in their normal position; but in several of

the thickest patches some of the scales were loose, and an extravasation of blood had taken place within the dermal sacs. On microscopical examination of this blood it was observed to be quite granular, containing no discs, and was freely mixed with oil globules. The under surface of the skin opposite to the patches where the scales were loose was inflamed and discoloured over an area larger than where the scales were loose, the tendinous attachment of the muscles to the skin was intact, and the muscles themselves were uninjured in any way.

No. 2, a male kelt.—This salmon had twenty patches of fungus on its body and fins, and its mouth was quite filled with it. The fungus on this fish was very rank; several patches were felted to five-eighths of an inch in thickness. The felting is caused in the first place by the filaments being twisted upon themselves and overlying each other, which prevents the spores escaping from the zoosporangia at the apex of the filaments in which they germinate and grow, and by the filaments sending out innumerable delicate fibres, which are woven by their own growth and the action of the water into a thick mat, in which the detritus of the river becomes embedded. The blood, mucus, and fæcal matter of this fish were examined in the same way as in the female, showing the same results. Several teniæ were found in the intestine, otherwise the viscera were quite healthy.

No. 3, a kipper grilse.—This salmon had twenty-four separate patches of fungus on its body, fins, and head, also a large patch seated on the mucous fold of the mouth, and involving both upper jaws and palate, which would cause difficulty of breathing, and the growth continuing would cause death from suffocation.

This fish looked a decided kelt, and was labelled as such by Inspector Johnston of Coldstream. However, on opening the abdomen I was surprised to find that the testes were not fully developed. The pyloric cæca and intestines were loaded with fat, and all the viscera were in a healthy condition, and, on the most minute and careful examination, nothing indicating disease of any of the organs could be detected. Externally this fish was disgusting to look on, as, in addition to the numerous patches of fungus on its body, several cicatrices on the head from former injuries gave it a most repulsive expression.

I also examined two salmon taken at Berwick-on-Tweed, at one of the Berwick Fisheries Company's stations, situated in the tide-way about one mile from the sea. One of those salmon I received from Sir Robert Christison, the other from Mr G. L. Pauline, secretary to the Berwick Fisheries Company. Both of those fish were affected with fungus, and were injured about the head and fins in a similar manner to those taken miles above the tide-way; the fungus also presented all its characteristic features. Both specimens were maiden salmon, and in excellent condition. They were both cooked, and were partaken of by sixteen persons, twelve of whom were fully informed that the fish were affected with fungus, four persons were not informed until after they had digested it. The former, myself included, all say that they knew no difference in either taste, colour, or smell from fishmongers' salmon; the latter say that I am only trying their nerves in saying the fish had fungus disease, as they had never eaten better.

I have also examined two other salmon, both of which were maidens. They were both from the Tweed river. One was presented to me by Mr Speedie, gamekeeper at the Inch, who saw it in a dying state and pushed it out of the river with a stick. This was a beautiful salmon, with only a few patches of fungus on its body and tail, which were easily rubbed off, leaving only a slight stain of a brassy hue where they were seated, and with the scales intact. A very large patch was seated within the mouth, involving both the upper and lower jaws, the palate and mucous fold in the upper part of the mouth, and extending to the gills, which were also thickly studded with parasitic crustaceans, from the combined effects of which it was dying of suffocation.

The other salmon was presented to me by Arthur Campbell, Esq., Randolph Crescent, Edinburgh. It was captured in the Tweed at Maxton. This fish was a maiden salmon, in high condition, and exceedingly fat and firm. It was injured about the forehead and nostrils from fungus having been seated upon them. The frontal bones were exposed, and appeared as if corroded by friction, and the skin around this part had begun to slough; no fungus adhered to the bare part of the bone, but the loose skin surrounding it was thickly coated with it. There were a number of patches of fungus on its body and fins, but no sloughing had taken place under them. I

have injected and preserved the stomach and pyloric cæca of this fish as examples of those organs in a high conditioned fish. It was cooked, and several gentlemen who partook of it pronounced it excellent.

By the kind attention of James Tait, Esq., of Kelso, I received a common river-trout and a minnow, both of which were captured near Kelso Bridge in Tweed river; both specimens were affected with fungus—the *Saprolegnia ferax.* I may here mention that I have noticed several able letters which have appeared in the *Scotsman* newspaper from time-to time, in which the writer states that the fungus is only a secondary attack, and that a primary disease of an inflammatory kind first affects the head and other parts of the salmon before the fungus can settle upon it. I do not for an instant doubt the fact that the writer saw fish with sores of the kind described by him upon them, when there was no fungus present to cause them. I can only say that, among all the fish which I have received for examination, consisting of salmon, sea-trout, smolts, common trout, greyling, and minnows, I have not seen one with a sore on which this fungus was not present; while on every fish examined there were some patches of fungus which could easily be wiped off, leaving only a slight stain, and in some instances no mark could be discerned, and no loosening and shedding of the scales or ulceration of the subjacent surface. Again, in every instance where the fungus was rank, long-seated, and felted, sores in every degree, from slight abrasion to sloughing, were found under them. With reference to the trout and the minnow before mentioned, the trout had fungus seated upon the gums of both the upper and lower jaws, which involved both the teeth and lips, and had spread upward and backward upon the head, and its destructive progress could be easily traced: first, the skin of the lips was broken in several places, and shreds of it were hanging loose, to which the fungus was adhering; while, as it spread backward over the nostrils and crown of the head, the skin and its pigment spots could still be seen intact where the fungus was seated, a portion of which had been carefully shed aside to expose the skin. On each of the pectoral fins a patch of young fungus was seated, and the mucous coat was seen through the fungus to be quite entire; the same appearance was seen upon the anal fin and

scaled parts of the body. The minnow had only one patch of fungus upon it, which was seated within its mouth on the inner margin of the right lower jaw; it filled the mouth, which was distended by its growth; and every other part of its body was free from fungus or blemish of any kind.

The reason why most of the fish affected with fungus are first attacked by it upon their heads may arise from various causes. All river fish present their heads to the downward current of the water whether they are swimming or at rest, and as the spores of the fungus are floating down with the stream, the heads of the fish are the first parts to come in contact with and be affected by them. Further, the mucous glands are most numerous and active upon the head of the fish, which is also more thickly covered with mucus than other parts of the body, and the spores which fall upon it adhere more readily; and the fins and tail, from their continuous waving motion, are more liable to arrest the passing spores than the parts of the body from which they spring, and, from this cause, are generally affected sooner than the bodies of the fish.

The numbers of the dead and dying fish of all kinds removed from the river Eden in 1878 by the police, and published by Mr Buckland in his report for that year, show that there were 1271 salmon, 140 fresh-water trout, and 40 brandlings or parr, being over 50 of the large fish to every one of the smaller. About 1000 of the salmon were clean fish, and it may be inferred that the trout and parr were also clean, which goes far to show that the so-called disease is as much a mechanical as a functional one. Further, from documents descriptive of the effects of the disease in the river Tweed, in the lower district, during this season 1879, which were collected by the police from taxmen and practical fishermen on the river, I find that the proportion of large fish affected, dead or dying—namely, salmon and sea-trout—is very great compared with the smaller fish, which were found to be affected in a similar way. The smaller fish alluded to consist of river-trout, greyling, smolts, perch, and grey mullet.

From observation of the fungus and of the fish affected by it, I am led to believe that the so-called salmon disease does not depend upon a pre-diseased condition of the fish. It is a true parasitic attack to which every fish in any affected river seems to be liable,

as every kind of fish, irrespective of condition, appears to be a proper nidus for the propagation of the *Saprolegnia ferax* when a living spore from that fungus attaches itself to it. While engaged during the spring and summer in the microscopic examination of the *Saprolegnia ferax,* I observed that as the season advanced many of the patches of fungus seated upon the fish were barren, consisting of spear-shaped filaments only, having no zoosporangia at their apex, and consequently they produced no zoospores; the filaments were long and very thin, and almost void of protoplasmic contents, indicating that the plant was losing its force and in a state of decay.

The *Saprolegnia ferax,* in all probability, is always present in our rivers in more or less active condition. It is believed that this fungus has two modes of reproduction, namely, by oospores and by zoospores. The oospores are few in number, and may be looked upon as ova, and they require sexual impregnation. They are called resting spores, from a belief that they remain dormant in the water for an indefinite period, which may continue for many years; and during this phase of their life they may germinate in limited numbers, providing only for the continued existence of the species. While in this state of abeyance there is no plague of fungus, from the ova only producing neutral or barren plants, which bear no fruit or seed. After a period, of longer or shorter duration, a season, or a series of seasons, may follow, during which an unknown influence arises, which acts upon the resting spores, by which they are stimulated to great reproductive energy; and the plants they produce being fruitful, the asexual mode of reproduction commences.

The zoospores are produced in podlike cases called zoosporangia, which are situated at the apex of the filaments, and may be looked upon as fruit or seed. They are the ciliated spores, and are the media by which the fungus is communicated to the fish. The zoospores are produced in great numbers, each zoosporangium containing from 100 to 150 of them. The oospores or ova are produced in a globular sac, which forms at the root ends of the filaments, or upon the roots themselves. Those sacs are called oogonia, and each sac contains a few oospores or ova, three or four, to nine, being the numbers I have observed in the four instances in which I have seen them, in the whole course of my investigations.

Suppose an oospore (resting spore) to be capable of producing, under favourable circumstances, a plant carrying 100 filaments, and each of the filaments to produce 100 zoospores, 10,000 germs would be derived from a single ovum or resting spore, every one of those germs being capable of producing a plant as productive as that from which it derived its existence, a multiplication of innumerable millions would be produced in a few days, the ciliated spores being as plentiful in the water as snow-flakes are in the air during a snow shower; and in this way the plague of fungus, the so-called salmon disease, is originated.

I obtained in April the living fungus from a greyling caught by Mr J. Willins, student of medicine, when angling in Keerfield Pool in the Tweed, near Peebles. It had been cut in two halves and the tail portion selected; it was packed in a tin vessel with wet moss, which had preserved the fungus in active vegetative growth, when I received it on the morning after its capture. A pale pink bloom was plainly visible over the whole surface of the matted fungus, and, when it was held up between the eye and the light, a new growth appeared to cover the older fungus on its outer surface to about one-eighth of an inch in height.

When examined under the microscope in water, free ciliated zoospores, which had escaped from the zoosporangia situated at the extremities of the filaments, were observed in motion—they moved in a fitful way, by short jerks, not by a continuous movement.

Those zoospores were pyriform in shape during the short time they were observed in motion; on becoming stationary the cilia disappeared, being probably withdrawn into the body of the spore, which then assumed a globular form. This change took place in a very short time—not exceeding ten minutes,—and while under observation minute projections became visible on the edge of the spore, which grew into delicate filaments of considerable length. I have succeeded in fixing the development of the fungus in this state, and it can be seen in various stages of growth, all of which were ciliated spores within the space of one hour.

This, the asexual mode of propagation, is remarkable for the rapidity with which it is accomplished. A few of those ciliated spores become attached to any part of either a healthy or a diseased

fish; in one hour the cilia will have disappeared and a filament of some length will have sprouted from the spore. Thus, in a single day, a fish, on which no fungus could be discerned, is to-morrow seen to be affected, and in three days is spotted or patched over with fungus from head to tail.

In the second or sexual mode of production of spores a short pedicle is pushed out from one of the sides of a filament on which a globular sac—oogonium—is formed, and within this sac a number of oospores are produced, which are spherical in shape and have a cell wall or envelope, and some are provided with a nucleus in the centre. These, after impregnation, escape from the oogonia, and are probably capable of living in the water for an indefinite period, in a dormant or resting state, until the conditions arise which are favourable for their germination.

It may be asked, how does the fungus affect the fish, and do any recover from its effects? The fungus produces a local irritation and inflammation of the integument, as is evidenced by the congestion, and even ecchymosis of the true skin, by abrading of the scales, and in the more advanced stages by ulceration and sloughing, affecting the whole thickness of the integument and mucous surface.

Wherever the fungus adheres and spreads, the function of the skin is necessarily interfered with. Light, which is so essential to the fish in promoting its pigmentary secretions, is cut off from a large portion of its skin. Endosmosis, exosmosis, and the secretion of the mucus for lubrication are destroyed, and in this way constitutional symptoms would be occasioned which, if the disease continued, lead to the death of the fish.

The second question, Do any fish recover from fungus attack? may now be answered more hopefully. The fishermen and watchmen on the Tweed report having seen several fish with new skin growing over the sores upon their bodies, from which this fungus had disappeared, and I am inclined to believe that this is so. A male kelt has been sent to me by Mr List, which was taken in tidal water below Berwick bridge. This fish is 2 feet in length, and weighs about three or four pounds; it is supposed to have been affected with fungus, and to have completely recovered from its effects. No particle of fungus could be found upon any part of its body, and

there was only one raw sore. This sore was only $\frac{5}{8}$ths of an inch in length and $\frac{3}{8}$ths in breadth. It had evidently been larger, and had a smooth healing border. All the upper surface of the head and snout were covered with skin, but very uneven over its whole surface, from depressions and projections which may have been caused by sores which have been healed over, and the hinder part of the operculum had an irregular cicatrix of considerable size upon it. The breast and belly, from the gill coverts to the vent, were blood-streaked and spotted, and there were brownish marks upon both its back and sides as if fungus had recently adhered to it. All the fins were entire,—not one ray was broken; and the fish as a whole looked remarkably well for a kelt, and if it had been affected with fungus, which I fully believe, its recovery has been almost perfect.

A salmon taken at some distance up the river, and which is affected with fungus, has been taken down to Berwick and placed in a box or corve, and is now anchored in the river, in the tideway, where the water is at all times less or more salt, and at intervals is towed out to sea, where the full influence of the salt water acts upon it; and when I last heard of it considerable improvement had taken place. Mr G. H. List has paid particular attention to the detection of any fish being affected with fungus disease in any of the coast fishing stations; and, after the most careful inquiry, no trace of any fish in the least degree diseased at any of those stations could be got, nor, as far as any fishermen either knew or heard of, was any salmon with fungus upon it ever seen in salt water.

I have tried to propagate this fungus upon dead flies, spiders, and other small animals, following the directions of Pringsheim, "N. A. A. L. C.," 1851, p. 417,* who says—"All that is required to obtain a living specimen of this singular plant is to allow the body of any small animal, such as a fly or spider, to float for a few days in rain water exposed to the light. By this method a crop of *Saprolegnia* may be obtained at any season." In this way I got a fungus upon the flies and spiders after an exposure of from twelve to twenty days, which on examination was found to be a common

* Cited by Dr Burdon Sanderson in his paper on the "Vegetable Ovum," *Cyclopædia of Anatomy and Physiology*, edited by Dr Todd.

mould exactly similar to that produced upon a solution of gum-arabic, gelatine, and meat infusions. I have tried to propagate the *Saprolegnia* fungus upon minnows, but without success hitherto, doubtless because the method adopted did not provide the proper means, there being awanting the necessary stimulus which exists in the river, or, what is more likely, the life of the fungus itself. The minnows were placed in a large glass vessel filled with town water from the tap. A piece of skin with this fungus adhering to it was taken from a salmon smolt and placed in the water along with them. In three days they had eaten up both skin and fungus, and remained unaffected. Several large patches of this fungus were then taken from the skin of a salmon and placed in the vessel along with them. In a few days it had all disappeared, and produced no effect. Another method was suggested by Mr G. H. List, who also kindly furnished me with material for the trial. Pieces of skin with this fungus growing upon them were cut from the bodies of dead salmon at the river side, and were put into wide-mouthed bottles, which were at once filled with river water, the skin not being allowed to dry. On receipt of the bottles the pieces of skin, along with the water in which they were brought, were emptied into the vessel among the minnows. The water in the vessel was not changed for three days, at the end of which time the minnows were still unaffected. Fresh water was then put in the vessel, and the pieces of skin retained in the water, which was changed every second day for eight days. The minnows were not disturbed by the pieces of skin. They nestled under them and nibbled every morsel of fungus from them, hiding and playing about them until they had to be removed from putridity. All the minnows are still alive and are in beautiful condition, taking food greedily, worms cut small and crystals of sugar being their favourites. They have been kept since 14th May till now, 12th July, and are as healthy and lively as when put in the vessel.

I have received from Thomas Key, Esq., Fellow of this Society, some information respecting a disease affecting the salmon in Lewis some years ago, which, from the sores of the skin of the head, resembled at a first glance a condition not unfrequently found on salmon affected with *Saprolegnia*. After examining my specimens, Mr Key wrote to me the following account of the disease in the

Lewis, which is of so much interest in connection with this subject that I append it to my communication:—

"From what I saw and heard from you, I am convinced that the disease from which the salmon in the Grimasto river in Lewis suffered some eleven years ago differed from the one you are now investigating. In the first place, we had *no trace of fungus*,—the affection was confined to the head, and although it destroyed many fish yet very many recovered from it. It attacked the fish in the sea, or, according to my theory of its origin, in the brackish water between the sea and the mouth of the river. It assuredly had not its origin in the river, or in the loch above it. There are many brown trout in our rivers and lochs, and none of them suffered. Neither among the multitudes of sea trout about us did I see one affected. The disease I am speaking of appeared about the middle of the season of 1868. As happens frequently in the Lewis, the months of May and June had been very dry, and for weeks before rain came, some time late in July, the fish had not been able to get up the river in consequence of want of water at its mouth. We were told that many fish had been found dead in the bay, and after rain had fallen and we were able to fish in the river and lochs, we then saw the nature and extent of the disease. Fish were found dead and dying in the river and at its mouth; others not too far gone, took the fly, and were caught. On the dead fish examined the whole of the upper part of the head was found covered with ecchymosed spots and ulcerated, the ulcers more or less superficial, and some with everted edges. In some the cartilages of the nose had been attacked, and one side of it cut out as it were by a corroding sore. When cut into, the bones and cartilages of the head were found to be softened, and there were marks of inflammation in the brain and membranes. The eyes were natural, the gills pallid but otherwise sound, and none of the fins affected. In the far advanced cases, among the fish caught, the softened appearance was very much the same, whilst in those less diseased the ulcers were few and small, the rest of the head being simply ecchymosed. In a great many fish recovery apparently soon commenced, the ulcers began to cicatrise, and the fluid in the ecchymosed spot was almost altogether absorbed. In every case, I may say, we observed the gill covers had a dull, white, leprous appearance, and in all the fish

that recovered the head was more or less *white,* and continued so for years afterwards; and even to this day, every now and then, a white head, as the gillies called the diseased fish, comes up from the sea.

"It is a curious and interesting fact that the condition of the fish was not affected in even the far advanced cases. Nutrition did not appear to have been interfered with. The body was as plump and fat and the pink colour as high as usual. I did not eat of those very far gone in the disease; of those less so I did eat, and found their flavour as in the healthy salmon. You will observe from what I have said that our disease, whatever might have been its cause, was a disease of the head, and confined to the head.

"So much for the form of our disease; now as to its origin. Whatever may have been the predisposing or its immediate cause, it is certain that the fish brought it with them from the sea, or, as in my opinion, acquired it in the tide-way in Loch Roch-Roag. They did not take it down with them when they went to the sea as kelts or smolts, but they brought it up from the sea in summer as grilse and fresh-run salmon. After mature consideration of all the attendant circumstances, I have come to the conclusion that the disease arose from the fish being kept moving so long up and down between the salt and brackish waters. With each flood tide they moved up in dense masses toward the mouth of the river, vainly looking for water sufficient to carry them into it, and, when the ebb came, going down again for two or three miles into the deep and comparatively salter water. This continuing for weeks, with the water in the bay becoming daily more shallow, the heat and bright sun during the day was sufficient, in my opinion, to account for the disease. I have already said the sea trout did not suffer, because very little water was sufficient to take them into the river, and they were kept outside for but a short time. Again, the fish in the Blackwater, a river within two miles of the Grimasto, had no disease—at least, I did not hear of any having been seen in it; the reason, as I think, being that at all times, except in the lowest neaps, the tide came up so near its mouth as to allow the fish to get into its lowest pools without much difficulty. Against my theory there is this to be said: as already mentioned, the island of Lewis has been subject within the last fifteen years, to my knowledge, to

many dry seasons; and notably in 1863 there was a very long-continued drought, proving so destructive to the salmon at Grimasto that it was said some 1500 fish were picked up dead on the shores of the bay and mouth of the river. I and my friends were not in the Lewis that year, and therefore I cannot speak as to the symptoms of that disease; but inquiry afterwards failed to elicit any evidence that they resembled the outbreak of 1868. . . . It may be that the fish in 1868 were in some peculiar abnormal condition *before coming up from the sea*, predisposing them to disease of the head; but at any rate I can give no other cause for the outbreak than those I have mentioned."

3. On the Form and Structure of the Teeth of *Mesoplodon Layardii* and *Mesoplodon Sowerbyii*. By Professor Turner, M.B.

The author in the first instance described the characters of the teeth of *Mesoplodon Layardii* from two specimens which had been collected during the expedition of H.M.S. "Challenger," under the scientific superintendence of Sir C. Wyville Thomson. The one specimen, a young animal, under 14 feet in length, was obtained at Port Sussex, East Falkland Islands, by Mr H. N. Moseley, F.R.S.; the other, an adult skull, was procured at the Cape of Good Hope.

The teeth of the younger animal, two in number, were imbedded in their alveoli in the lower jaw. Each tooth consisted of a small triangular denticle or crown projecting outwards, and slightly upwards from the middle of the upper border of the fang. The denticle measured 4-10ths inch in its longer diameter, the fang was 2 inches by 8-10ths. At the base of the fang was a cleft 2-10ths inch wide, which communicated with a pulp cavity that was prolonged almost to the apex of the denticle.

The denticle was invested by enamel, subjacent to which was a well-defined mass of dentine, which was prolonged as a thin layer almost down to the cleft at the root of the fang. The fang was invested by cement, which was separated from the dentine

by an opaque layer, consisting of a granulated matrix containing numerous branched and anastomosing vascular canals, like the Haversian canals of bone. A similar layer was prolonged into the pulp cavity, so as to line the dentine on its inner surface. This layer is apparently to be regarded as a modified form of vaso-dentine.

The teeth in the adult mandible were formidable tusks, which curved up the sides of the beak on to its dorsum, where they decussated across the middle line. Each tooth was 14 inches long, 7½ inches of which had protruded beyond the gum. It consisted of a triangular denticle and a strap-shaped curved shaft. The denticle was somewhat smaller than in the young tooth, and the enamel was almost entirely worn off its surface. The size of the tooth was therefore due to the enormous development of the fang which formed the strap-shaped shaft. The shaft consisted for the most part of a cortical layer of cement investing an opaque central band, which had the structure of the modified vaso-dentine of the younger tooth. 7-10ths of an inch from the summit of the shaft was a minute mesial chink 1-10th inch long, which represented the pulp cavity, but the rest of the shaft was solid throughout. The summit of the shaft was more complicated in structure, and consisted from without inwards of the following layers:—cement, opaque modified vaso-dentine, opaque vaso-dentine, dentine, opaque modified vaso-dentine. When traced from the summit to the sides of the shaft the dentine and vaso-dentine disappeared, and then the two layers of modified vaso-dentine blended with each other and formed the opaque central band of the rest of the shaft. The size of the fang is due to the great growth of the cement and the tissue of the opaque central band. The teeth of this specimen are larger than in any of the previously recorded specimens, and the animal from which they are obtained was probably an old male.

The structure of the teeth of *Mesoplodon Sowerbyii* was examined from the skull described by the author in the "Transactions of the Royal Society, Edinburgh," 1872, vol xxvi. Each tooth was laterally compressed, and formed almost an equilateral triangle, and the crown was not separated from the fang by any sharp line of demarcation. The tooth consisted in great part of dentine, which in the crown was invested by a layer of not very strongly marked enamel.

The dentine extended down the fang to the sides of the narrow cleft at its base, which communicated with the pulp cavity. This cavity, bounded by the dentine, was contracted at the base of the fang, but dilated into a considerable space in the body of the tooth. The fang was invested by cement, but between the cement and dentine a layer of modified vaso-dentine was situated which increased in thickness in the lower part of the fang, whilst the dentine became thin. The structure of this tooth was then compared with that of the adult *Mesoplodon Sowerbyii* described by Professor Ray Lankester.*

The teeth both of *M. Layardii* and *Sowerbyii* in their non-erupted stage do not materially differ in structure from the ordinary human or carnivorous teeth, for the crown is covered by enamel, and the fang by cement, whilst the great body of the tooth consists of dentine, in which is a well-marked pulp cavity. The exceptional structure of these teeth in the erupted stage is due to the disappearance of the enamel from the crown, to the cessation in development of the ordinary dentine, and to the excessive formation in the adult *Sowerbyii* of osteo-dentine, and in *Layardii* of modified vaso-dentine, which cause the fang to assume unusual dimensions.

The following Gentleman, having been duly recommended and balloted for, was elected a Fellow of the Society:—

James Abernethy, V.P. Inst. C.E., Prince of Wales Terrace, Kensington Garden, London.

Monday, 16th June 1879.

Professor MACLAGAN, Vice-President, in the Chair.

The following Communications were read:—

1. Atomicity or Valence of Elementary Atoms: Is it constant or variable? By Professor Crum Brown.

* "Quarterly Journal of Microscopic Science," 1867, vol. vii.

2. Action of Heat on some Salts of Trimethylsulphine. By Professor Crum Brown and J. Adrian Blaikie, D.Sc. No. IV.

I. The carbonate of trimethylsulphine is obtained by the action of carbonate of silver on the iodide of trimethylsulphine. The solution of the salt may be evaporated to a syrup in the water-bath. On standing for some weeks over sulphuric acid *in vacuo* it crystallises out in exceedingly hygroscopic prismatic crystals, containing water of crystallisation, and having a strong alkaline reaction.

Heated in the air to 100° the salt gives off water, sulphide of methyl, and carbonic acid. Heated in a sealed tube to 100° C. for about eight hours it was almost entirely decomposed, gave off a gas consisting entirely of carbonic acid, and yielded two layers of liquid —the upper, sulphide of methyl; the lower, water and methylic alcohol. The decomposition is expressed by the equation—

$$\{(CH_3)_3\}_2CO_3 + H_2O = 2(CH_3)_2S + CO_2 + 2(CH_3)OH\,.$$

II. The metaphosphate of trimethylsulphine is obtained by the action of metaphosphate of silver on the iodide of trimethylsulphine. The metaphosphate of silver was made from glacial metaphosphate of soda (Graham's salt) by precipitation with nitrate of silver. The metaphosphate of trimethylsulphine does not crystallise, but on evaporation leaves a colourless hygroscopic glass, containing some water.

The salt, when acted upon by heat, gives off sulphide of methyl, and the resulting product is at the same time decomposed, leaving free metaphosphoric acid. On further heat being applied the mass slightly chars.

III. The ferrocyanide of trimethylsulphine is obtained by the action of ferrocyanide of silver on the iodide of trimethylsulphine. On evaporation of the solution the salt crystallises out in pale-green transparent plates; they are not hygroscopic, and the salt gives all the reactions of an alkaline ferrocyanide. On drying over sulphuric acid or phosphoric acid, the crystals lose their water of crystallisation. Analysis leads to the formula $\{(CH_3)_3S\}_8Fe_2Cy_{12} + 18H_2O$.

The salt when heated to 220° C. gives off sulphide of methyl along with other products, including hydrocyanic acid, but does not

melt. The residue is a brown powder, which on being further heated is carbonised, no definite compound being obtained.

IV. The ferricyanide of trimethylsulphine is obtained by the action of ferricyanide of silver on the iodide of trimethylsulphine. On evaporation of the solution the salt crystallises out in pale orange-yellow transparent plates, which effloresce in the air. The salt gives all the reactions of an alkaline ferricyanide. On drying over phosphoric acid the crystals lose all their water of crystallisation. Analysis leads to the formula $\{(CH_3)_3S\}_6Fe_2Cy_{12} + 15H_2O$. The salt when heated behaves similarly to the ferrocyanide.

3. Comparison of the Salts of Diethylmethyl-sulphine and Ethylmethylethyl-sulphine. By Professor Crum Brown and J. Adrian Blaikie, D.Sc.

(*Abstract.*)

It seemed to the authors to be desirable to ascertain the mode in which the salts of diethylmethyl-sulphine and ethylmethylethyl-sulphine respectively decompose when heated.

They prepared the iodides by the method described by Krüger,* whose observations on the iodides and chloroplatinates they substantially confirm.

The benzoates were prepared from the iodides by action of benzoate of silver. They are exceedingly soluble substances, and were only obtained as thick syrups. Heated to between 110° and 120° C. they decompose in exactly the same way, yielding benzoate of methyl without any benzoate of ethyl.

4. On the Bursting of Firearms when the Muzzle is closed by Snow, Earth, Grease, &c. By Professor George Forbes.

It is well known that if an ordinary fowling-piece, charged with shot or ball, have touched the ground or snow, so as to close the muzzle of the gun, or if the muzzle of the gun be in any way artificially closed with grease or other substances, the fowling-piece is certain to burst at the muzzle when it is discharged. This would not be the case if, instead of firing a shot, a piston were driven up the tube by hand. In this case the compressed air would drive out

* *Journal für practische Chemie*, xiv. 193–213.

the opposing plug, which offers but a very feeble resistance to the internal pressure. These facts, thoroughly well authenticated, have not, to my knowledge, received a satisfactory explanation, though a clear idea of the conditions of the case is all that is required to explain this, at first sight, anomalous behaviour.

The explanation lies in the fact that the charge travels along the bore of the gun, if not with the same velocity as, at least with a velocity comparable to, that of the transmission of pressure through the air, *i.e.*, the velocity of sound. Thus, as the charge advances along the barrel it is continually compressing the air immediately in front of it; but this pressure gets no relaxation by expansion into the front part of the barrel. The compression, of course, generates heat in the air, which increases the velocity of sound through it. But this does not affect the question in its general bearings. It is sufficient to notice that the snow, &c., is driven out with the full velocity of the charge (neglecting the weight of the snow-plug compared with that of the charge). But before the plug can be driven out with this great velocity the pressure behind it must be very great.

Let m = the mass of the snow-plug.
g = the force of gravity.
v = velocity of the bullet or wad when close to the plug (*i.e.*, on leaving the gun).
p = the pressure of the air driving out the plug.
A = the sectional area of the bore.
b = the length of the snow-plug.
ρ = the density of the snow-plug.

The work done in giving to the mass m a velocity $= v$ is

$$w = \frac{1}{2} m v^2 .$$

But w is performed by the pressure pA acting through the distance $\frac{b}{2}$.

$$\therefore \quad w = \frac{1}{2} pA . \frac{b}{2} .$$

$$\therefore \quad pAb = mv^2 .$$

$$p = \frac{mv^2}{Ab} = \rho v^2 .$$

Thus, the pressure at the muzzle of the gun is independent of the diameter of bore and length of plug.

To take a particular example, let $v=1000$ feet a second, and let $\rho=$ the density of water, so that

$$p=gh\rho$$

when h is the height of the column of water producing an equal pressure—

$$gh\rho=\rho v^2$$

$$h=\frac{v^2}{g}.$$

If w be the weight of a cubic foot of water, $p=wh=w\frac{v^2}{g}$ is the pressure on the square foot.

Now, $w=72$ lbs. and $g=32$ and $v^2=1{,}000{,}000$;

$$\therefore \quad p=\frac{72}{32}\times 1{,}000{,}000 \text{ lbs. on the square foot;}$$

$$\text{Or,} \quad \frac{1}{144\times 2240}\times\frac{72}{32}\times 1{,}000{,}000 \text{ tons on the square inch}$$

$$=7 \text{ tons on the square inch.}$$

A pressure which the muzzle of a shot gun is not constructed to withstand, and the theory shows that this great pressure can be produced even by a plug of snow or grease of the shortest length movable inside the barrel with the greatest facility. If the velocity of the ball or wad be less than that of sound the snow-plug is not driven out quite suddenly, and if the velocity be small enough the snow-plug is driven out before the ball or wad reaches the muzzle.

5. On some New Bases of the Leucoline Series. Part III. By G. Carr Robinson and W. L. Goodwin.

Monday, 7th July 1879.

Professor MACLAGAN, Vice-President, in the Chair.

The following Communications were read:—

1. Notice of Striated Rocks in East Lothian and in some adjoining Counties. By David Milne Home, LL.D.

I know no more interesting problem in geology than the question, What was the great agency which brought the surface of

northern Europe into the condition in which it is now occupied by man? and it seems marvellous that geologists should not yet be agreed as to what that agency was.

Our own country of Scotland is strewed with boulders, many of immense size, and which we allow have been somehow transported to their present sites from remote regions. Rocks on our hill-sides have been ground down, smoothed, and striated by ponderous bodies which have come against and rubbed upon them. Almost everywhere there are deep beds of clay, sand, and gravel forming knolls and elongated ridges, not only on low-lying districts, but even on our highest hills. These things have been attracting attention and provoking discussions for more than sixty years; but no explanation has yet been arrived at, which meets with general acceptance. Some geologists insist on the agency of an ice-sheet, like that in which Greenland is wrapped; Others stand up for local glaciers, such as exist in Switzerland and Norway. Some suggest icebergs and other forms of floating ice, in a sea which submerged the country. Each of these theories has its partisans; for no crucial test has been discovered to indicate which of them, or whether any, is well founded.

The Transactions and Proceedings of our Society contain many papers regarding these phenomena. Of these papers, the earliest probably was by Sir James Hall, so long ago as the year 1812, and he was followed by M'Laren, Chambers, Fleming, and many other Fellows of our Society, who specially devoted themselves to this branch of geological research.

The last paper published on this subject in our Proceedings, was by our colleague, Mr David Stevenson, who described a portion of the hill in East Lothian known as North Berwick Law, which was found by him to have been ground down, smoothed, and striated. These effects he ascribed to the agency of a glacier, which came from the westward against the hill, first smoothing the rocks on its north side by the heavy pressure of the ice, and afterwards scratching the smoothed surface by hard stones incased in and protruding from one side of the glacier. Mr Stevenson suggested that the glacier might even have been, and probably was, of such dimensions as to have enveloped the whole of the Law, which reaches a height above the sea of 612 feet.

At the close of his paper Mr Stevenson expressed an opinion

that if the rocks of Stirling Castle, Craigforth, and other places were examined, interesting and instructive traces of similar glacial action might be discovered.

To this suggestion of an inquiry for cases of a similar kind, I am now here to respond, and with that view to lay before the Society an account of several striated rocks in East Lothian, Stirlingshire, and other places; I feel sure that Mr Stevenson himself will deem these cases not the less interesting, though they should warrant conclusions different from those he suggested.

I. East Lothian Striated Rocks.

The first of these which I mention, as the least complicated, are in the village of Linton.

The rock is a claystone porphyry. Several smoothed patches of rock occur here, and two of these show striations on surfaces from 3 to 4 square feet in extent.

One of these smoothed rocks is *horizontal* or nearly so; and on it the striæ have a direction W.N.W. and E.S.E.

The other smoothed rock *dips* towards the north, at an angle of about 35°, and on it, the striæ run due *east* and *west*.

The difference between the directions of the striæ of these two rocks, which are only a few yards apart from one another, may be accounted for by the fact that the same agent which produced striæ in a certain direction on a *horizontal* surface, would, *if that agent could be easily deflected*, not produce striæ in the same direction on a *sloping* surface. It would have less power to move up an inclined plane, but would move along it more horizontally.

What the striating agent was here, and in what direction it moved, is made manifest by the following facts. Both patches of rock were, when I examined them, still partially covered by a coarse clay, full of stones or pebbles, many of which were hard and angular, but some were soft. There were among them bits of coal and limestone, which must have come from the westward, as in East Lothian there are no coal or limestone strata to the east of Linton. In one of the smoothed patches there were two small hollows or depressions, which had interrupted the continuity of some of the striæ. These depressions on their inner surface showed a vertical wall on their west side, and a sloping wall on their east

side, indicating that the smoothing agent had partially entered the hollow, and had worn down a portion of the east side.

Assuming that the general course of the striating agent here was from W.N.W. towards E.S.E., it is quite intelligible that when this agent, *if of a flexible nature*, impinged on a rock surface dipping to the north, its direction would change so as to be more to the eastward.

There is another rock of larger dimensions about a mile to the west of Linton village, on the line of the North British Railway. It is about 25 feet in length and about 18 feet in height, and

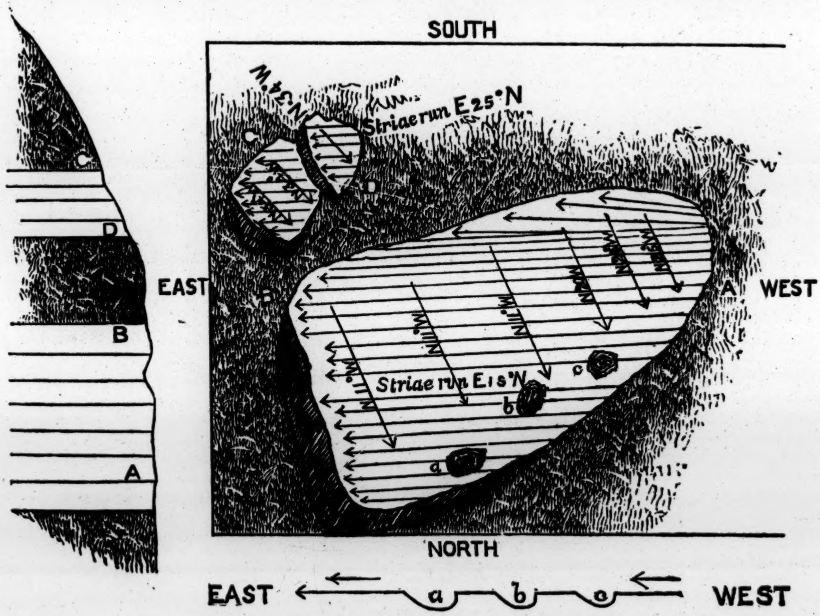


Fig 1.—Rock on Railway, near Linton.

presents a surface nearly vertical. It is on one side of a gully through which the railway passes, the rock being on the south side of the line.

The rock was discovered and exposed to view, when an excavation for the railway was made into a thick bed of boulder-clay which occurred here. The rock now seen had previously been entirely covered by the clay. With the consent and the assistance of the railway authorities, I had an additional portion of the rock at its west end stripped of the clay, to the extent of several square yards, when more smoothing and striation was brought to light.

Besides the rock which forms the lowest and principal part of

the bank, there is a small patch of rock, about 10 feet long by 4 feet wide, at the top of the bank, also smoothed and striated.

Both rocks dip rapidly, the upper one at an angle of about 55°, the lower one in its lowest part is vertical.

The principal rock is AB on the preceding diagram (fig. 1) and the smaller is CD.

The dip of each is indicated by the section at one side. The two rocks do not front exactly in the same direction. The lower rock fronts N. 11° W. for two-thirds from its east end; but near its west end it fronts about N. 30° W. The upper rock fronts about N. 34° W.

The striæ on both rocks are exceedingly numerous. There is not half a square inch on either without ruts or scratches. Some of the striæ on the larger rock are from 5 to 6 feet in length, and from $\frac{1}{4}$ to $\frac{1}{2}$ an inch in depth, and from 2 to 3 inches wide.

There is, however, a difference in the depth of the striæ which deserves notice and explanation. In the upper rock CD, they are much deeper and wider than they are generally in the lower rock. But in the lower rock, the grooves or ruts are deeper at the west end than towards the east. An explanation is suggested by the way in which the rocks front. If, as the rocks in Linton village indicate, the striating agent came from W.N.W., the obstruction to its progress eastward would be greater by a rock facing N. 34° W. than by a rock facing N. 11° W. Hence to overcome that obstruction, more pressure by the striating agent would occur, and deeper ruts in the rock surface would be made in the former than in the latter case.

It may be mentioned, that whilst generally the striæ on the large rock AB are horizontal, near the top they rise towards the east at an angle of about 4° or 5°. It may be supposed that if the striating agent consisted of a mass of detritus, the weight of the mass would keep the striating tools in the low parts of the mass in a line more or less horizontal, but that at or near the top of the moving mass, its component parts would rise, so as to obtain a direction more in conformity with the normal movement towards E.S.E.

In the upper rock, CD, there is a vertical joint, as shown in the diagram. It has had the effect of breaking the continuity of the striæ. The joint has a breadth of 6 or 8 inches, forming a face

which fronts N.N.E. There are no striæ on this face, as a force coming from W.N.W. would not strike on it.

In the lower rock there are small cavities or depressions (*a*, *b*, *c*) in the general surface, in consequence of which the continuity of the striæ has been interrupted. When I first examined the rock, two of these cavities were filled with boulder-clay. The west sides of the cavities are vertical, but the east sides are smooth and sloping, having apparently undergone attrition by the materials passing over them from the west. This point is further explained by the section EF at the bottom of the diagram.

Besides the smoothed and striated rocks in Linton and near it, just described, there are cases of the same kind at the following other places in East Lothian, all of which I have examined:— viz., North Berwick Harbour, Kingston, Dirleton, Redside, Balgone, Whitekirk, Smeaton, and Rhodes. At each of these places there are indications of a movement from the westward, in accordance with what is shown by the Linton rocks, and also by the striæ on North Berwick Law, as inferred by Mr Stevenson in his paper.

I have also within the last few days had an opportunity of visiting North Berwick Law, and of seeing the rock described by Mr Stevenson. It is the only part of the hill on which I could find smoothing and striation; and it is important to notice that it is the N.W. part of the hill on which these markings occur. I regretted to find, that since Mr Stevenson's inspection and report in the year 1875, most of the smoothed and striated rock has been destroyed by quarrying. But some parts remained; and having in my hand a photograph of the rock, which Mr Stevenson had kindly given to me, I was at no loss to see what had been its principal features. I brought away a specimen of the smoothed surface, which I detached, and on part of which striæ occur. This specimen I now exhibit to the Society.

I found that the smoothed surface generally dipped towards the N. or N.W. at an angle of from 65° to 70°.

Parts of the smoothed surface faced N.W., other parts faced various points towards due N. and even N. by E.; but wherever the rock faced a more easterly point, there was no smoothing. The specimen on the table shows these differences, because it has two faces meeting, forming an angle between them, and fronting in different directions.

The only parts of the smoothed surface striated were those fronting N.W. by N., or a few degrees on either side of that point.

The striæ and ruts were quite as numerous and near one another as on the North British Railway rock.

Their direction was from W. by S. or W.S.W., and most of them were approximately horizontal.

Some of the ruts, especially at their west ends, were deep, showing, as Mr Stevenson says, that the striating agent, whatever it was, must have pressed on the rock with great force. Mr Stevenson also mentions another important fact, which I observed, that *some* of the ruts were inclined along the smoothed face *up towards the east* at angles of from 4° to 20°.

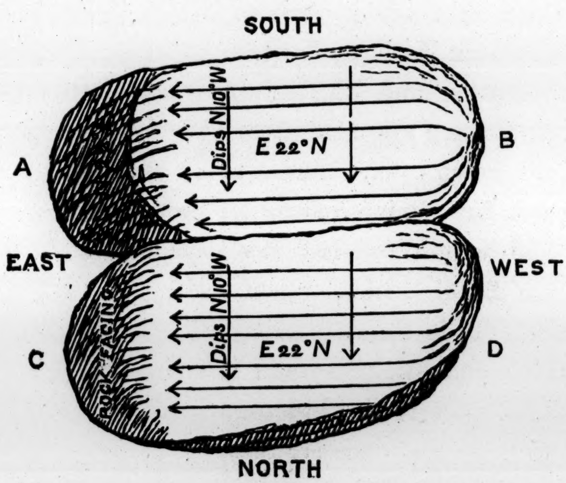


Fig. 2.—Part of Rock, North Berwick Law.

The particular direction in which the striating agent came on the rock from the westward may be inferred, by considering that if it came in a direction *parallel* with the rock it might smooth but would not rut or groove, as there would be no severe pressure. Nor, on the other hand, would it produce grooves or ruts, approximately horizontal and parallel, if it struck the rock *at right angles.* A line parallel with the rock would be S.W., and a line at right angles to it about N.N.W. The intermediate point would be W.N.W., from which direction, therefore, it may be inferred that the striating agent moved upon North Berwick Law.

The annexed, fig. 2, AB and CD, shows a portion of smoothed rock with striæ and ruts. These were only upon the rockface fronting

N. 10° W. At B and D the rock was well smoothed and rounded, and very slightly striated. At the east ends, which faced N. 22° E., there was no striation and little smoothing.

I may add, that some of the rocky ridges in East Lothian at the places above mentioned, present another feature besides smoothing and striation deserving notice, and bearing on this subject.

These ridges, generally speaking, trend or run in a direction E.N.E. and W.S.W. On their N.W. sides, at the base of the ridge, there is often a deep trench, running for some hundred yards, and now filled with water forming little lakes; as, for example, at Smeaton, Balgone, and on the north side of North Berwick Law. The probability is, that the agent which smoothed and striated the *upper* parts of these rocks, had scooped out the softer materials lying along their *base* on their north flanks, forming thereby, as it were, a gigantic ditch or trench on these sides.

II. Striated Rocks in adjoining Counties.

Referring now to striated rocks elsewhere—I would first mention the rock at Stirling Castle, near what is called Drummond's Cemetery,* at a height of from 220 to 230 feet above the sea. The rock

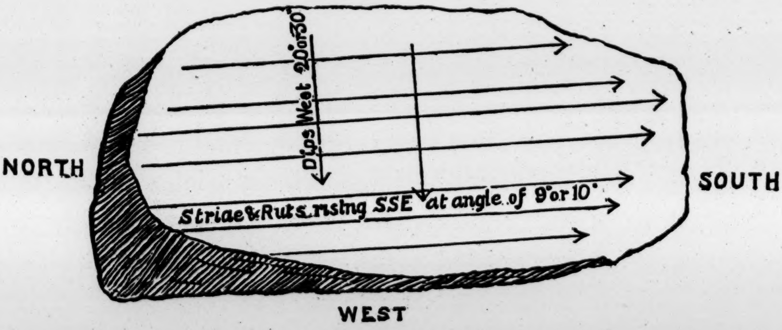


Fig. 3.—Smoothed and Striated Rock, Stirling Castle, 15 × 8 Feet.

there presents a surface which has evidently been smoothed by the friction of some agent which has passed over it. The surface of the rock dips due west at an angle of from 20° to 30°. There are

* The observations recorded in this paper were made by me several years ago. But I regret to find that by the formation of a new walk in the Cemetery, most of the smoothed and striated rock referred to has been removed. A very small portion only remains. This I discovered since the paper was read, and after the proof sheets had come to me for revisal. Happening then to be in Stirling, I went to the Cemetery and found what I have now stated.

numerous striæ on this rock, running about S.S.E., and in that direction rising up along the surface of the rock at an angle of about 9°. Fig. 3 illustrates these facts.

This direction of the striæ upon the surface of the rock, *sloping in the direction it does*, would result from the rock being impinged upon by an agent of great weight and power, moving from W.N.W.

That such was the normal direction of the movement in this district is proved by many markings on other parts of the Stirling Castle rocks. For example, there are several places where there is a narrow defile or gully between the rocks running in a direction approximately W.N.W. In these gullies, though the sides are *smoothed* by the friction of some body or bodies passing through them, they are not *striated*, the pressure on the sides not having been sufficient to produce striæ, these sides having been parallel to the movement of the bodies passing between them.

There are other hills in Stirlingshire which indicate smoothing and striation. Thus, on the Abbot's Craig, near the base of the Wallace Monument, at a height of 334 feet above the sea, there are well-rounded bosses of rock with deep groovings which run N.W. and S.E.

So also at Torwood, about 5 miles to the S.E. of Stirling Castle, as Sir James Hall first pointed out, there are striations on the rock bearing N.W. and S.E., at a height of from 330 to 350 feet above the sea.

Coming now to Mid-Lothian,—on the top of Allermuir Hill, one of the Pentlands, at a height of 1647 feet above the sea, there are striations on the rocks, as vouched by Mr Croll and by Mr John Henderson. On others of these hills, at heights of 900 feet, as vouched by Mr M'Laren, and of 1100 feet, as vouched by Mr Henderson, there are striated rocks. All these are of the same character as those in East Lothian.

Now, with reference to the agent by which these striations may be supposed to have been produced, it is important to keep in view, that at most of the places just mentioned, even at the highest levels, there is abundance of clay and gravel.

Thus, Professor Geikie, in his "Memoir on the Geology of the Neighbourhood of Edinburgh" (p. 126), says: "Boulder clay lies along the N.W. flanks of the Pentlands to the height of at least 1300 feet;" and he adds, that "where the clay has been recently removed, we usually find the rock below polished, groeved, and

scratched, in a direction nearly E. and W., or E.S.E. and W.S.W."

Much to the same effect, Mr John Henderson of this city, an excellent practical geologist, refers to two localities in the Pentlands where clay beds occur full of gravel and hard pebbles. One of these places is Glencorse, at a height of 900 feet, where he says there "is a stiff reddish clay full of well-rubbed and scratched stones, and differing in no way from the boulder-clay of the lower districts." The other locality is 3 miles distant, at a height of about 1100 feet, where (Mr Henderson says) the clay is of the same character as the last-mentioned, and covered by a great deposit of gravel and boulders.

That ruts and striæ on the smooth surface of a rock can be produced by the passage and pressure of hard angular stones, is a fact established by many cases carefully observed. I remember many years ago having witnessed the effects produced by the giving way of a large embankment on the North British Railway at Dunglass Burn. The culvert under the embankment had become choked. Water accumulated on the upper side, till at length the embankment gave way. The materials composing it rushed down the valley with much force; Rocks and large blocks of stone along the valley were scratched and rutted by the *debris* passing over them. I thought the circumstance so instructive that I procured one of the large striated blocks, on which no less than 50 or 60 striæ had been made, and deposited it in the Museum of this Society. I have sought for this specimen, to show it this evening, but without finding it.

III. Information obtained by Study of Boulders.

Whilst considering the agency which produced *striæ* on *rocks*, it is not irrelevant to keep in view the light thrown on the subject by *Boulders*.

Boulders are, like striated rocks, found at all levels, from the sea-shore to the tops of the highest hills. Many of these boulders are traceable to parent rocks situated in the western districts, and therefore show, as the striated rocks do, an agency of great power which moved from the west. For example, the mica slate boulder on the Pentland Hills, 8 or 10 tons in weight, at a height of 1400 feet above the sea, first noticed by Mr M'Laren, must, as he says,

have been carried from about Loch Vennacher or Loch Erne (which is the nearest place for mica slate rocks), distant about 50 miles; and to reach the Pentlands, must have been carried in a S.E. direction across the Ochil range and the valley of the Forth.* A few days ago I was so fortunate as to fall in with a small boulder of red granite, on the farm of Kingston, 2 miles south of North Berwick. This East Lothian granite boulder most probably came also from the Grampians, and travelled 20 miles farther than the Pentland boulders.

There is a large boulder of Carboniferous Sandstone on the Lammermuir Hills, at a height of 1500 feet above the sea, first taken notice of by Professor Geikie in his "Memoir on the Geology of East Lothian," which must in like manner have come from the N.W., where rocks of that description are situated. This boulder led the Professor to say, that it "seemed to indicate a submersion [of the land] to the extent of 1500 feet."

On the farm of Drylaw, near Linton, there is a boulder, with striæ on it, to which my attention was some years ago called by Sir Thomas Hepburn of Smeaton. It was met with on the occasion of a deep drain being made through boulder-clay. The boulder is of basalt, very similar in composition to a rock near the Gullane Hills, situated to the west. The length of the boulder is 6 feet, its width about 3½ feet, and its depth about 3½ feet.

It was narrower at one end than at the other, and that end pointed N.W.

The cutting of the drain having shown striæ on the north side of the boulder near its west end, Sir Thomas Hepburn, on whose land

* With reference to this boulder, Mr Maclaren says:—"To reach the spot where it lies, it must have passed over extensive tracts of country from 500 to 600 feet lower than this spot. Even were all Scotland converted into a *mer de glace*, like Greenland, no moving mass in the shape of a glacier could carry this boulder (and there are many such) from its native seat in Perthshire or Argyleshire to Habbie's Howe. An iceberg from the West or North Highlands, and floating in a sea 1500 or 2000 feet above the present level of the Atlantic, is an agent capable of effecting the transportation of the stone, and offers, I think, the only conceivable solution of the difficulty" (*Edinburgh New Philosophical Journal* for 1846, vol. xl. p. 138). Referring to this boulder, and to another of mica slate on the Pentlands, weighing about ¾ of a ton, the late Professor Nicol says:—"When it is considered that these masses must have been carried upwards of 40 miles in a direct line, floating ice seems the only agent to which their transportation can be ascribed" (*London Geological Society Journal*, vol. v. p. 23).

the boulder lay, had an excavation made in the boulder-clay, along the south side of the boulder, to see if there were striæ on it also. It turned out that there were.

I found that on the north side of the boulder the striæ ran in a direction from W.S.W., and on the south side from N.N.W.

The annexed diagram (fig. 4) represents this boulder, with its north and south sides striated at the west end of the boulder. The striæ were rather more numerous on the north side, AB, than on the south side, CD.

Evidently it was the same agency which produced the striæ on both sides. By coming against the boulder at its west end, this agency, whatever it was, had separated into two streams or *coulées*, and had marked both sides, by pressing upon them as it passed.

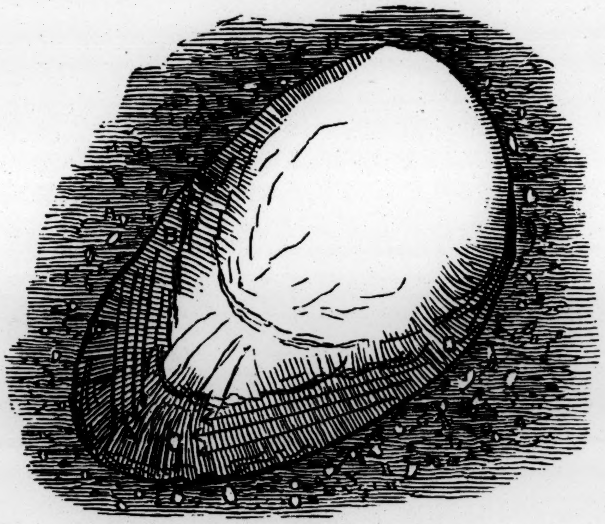


Fig. 4.—Drylaw Boulder, near Linton.

Now this could have been effected only by a body coming from a direction intermediate between N.N.W. and W.S.W., *i.e.*, about W.N.W. The agent which thus divided into two streams must have consisted, not of an inflexible solid body, but of "a mass," as Mr Stevenson calls it, capable of separation. The clay in which the boulder was buried was a body of this character. It contained numbers of pebbles, as usual in boulder-clay, some so hard as with pressure to be capable of smoothing and scratching any rock against which they were pressed. Sir Thomas Hepburn showed to me a portion of a small granite boulder which he had picked out of the clay.

IV. Conclusion.

The facts which I have stated seem to warrant the theory, that when these rocks and boulders were striated, this part of Europe was submerged beneath a sea which reached to the tops of our highest hills, and that ice floated on this sea, carrying boulders and discharging them wherever the ice melted or was arrested by submarine obstructions.

When the sea stood at a high level, effects would be produced on our hill tops and hill sides. As the sea subsided, similar effects would be produced at lower levels.

During the whole period when Great Britain was submerged, we know that the sea was of so low a temperature as to be suited for floating ice. The shells found at a height of 1800 feet in the west of England contain several species of an arctic type. These arctic species occur likewise in Scotland, but at lower levels, when, therefore, probably the sea had greatly subsided.

What all arctic voyagers report as having been seen by them may, therefore, have occurred in Scotland; for they saw rocks smoothed and striated,—and boulders occupying such positions,—as to satisfy them that icebergs, and floating ice in various forms, were the agents which had been, and were then, at work in these phenomena.

With regard to the glacier theory, it seems to me that to account for the striated rocks and boulders *in the valley of the Forth*, that theory is attended with insuperable difficulties. If the striations on North Berwick Law, and in East Lothian generally, were due to a glacier, so must also have been the striations on Stirling Castle rock, the Abbot's Craig, Torwood, and the Pentland Hills. This glacier, therefore, must have been of gigantic dimensions, filling the whole valley of the Forth, reaching to a height of 2000 feet above the present sea-level, and to a depth of at least a hundred feet below it, with a width of some 20 or 25 miles, when at the mouth of the present Firth of Forth. But where could be the birth-place of such a glacier? Certainly not in the valley of the Forth; for the head of the valley is only 220 feet above the sea, that being the height of the ridge which separates the valley of Loch Lomond from the valley of the Forth.

But even if it were possible to suppose that a glacier had been formed at the head of the valley, and that it overspread East Lothian, I find it difficult to understand how rocks, so nearly vertical as those at North Berwick and on the railway could have been striated in the way suggested by Mr Stevenson. Stones or pebbles at the *bottom* of a glacier might, by the weight of the glacier upon them, be made to striate rocks below the glacier, these rocks forming the floor upon which the glacier moved. But rocks which were *vertical*, or nearly so, could not be so operated on; and there are no observations to warrant the supposition that pebbles are ever imbedded in the ice and protruding from the side of a glacier so as to groove the vertical sides of a hill.

The infinite number of the striæ on these steep rocks at Linton and North Berwick Law is also a circumstance most unfavourable to the supposition that they were formed by stones protruding from the side of a glacier. On the other hand, a thick mass of boulder-clay, full of hard pebbles, would be quite capable of striating, if the clay containing them were pushed forward and pressed on a rock surface.

There is another feature which bears on the nature of the striating agent. Mr Stevenson correctly pointed out that whilst most of the ruts and striæ on North Berwick Law were horizontal, some striæ rose upwards towards the east at angles from 4° to 20°. On the railway rock near Linton I observed the same feature. If the striæ were formed by stones protruding from the side of a glacier, they would all be parallel. Their want of parallelism can be more easily explained if a mass of detritus was the agent.

There is one circumstance which appears almost conclusive against a glacier having been the agent of striation, at all events in the valley of the Forth, and strongly favourable to the theory I have indicated in this paper.

This circumstance is the facility with which the striating agent is shown to have been *deflected* from its normal course by trivial obstructions. Thus at Linton, in consequence of the rock on which the striating agent impinged dipping due north, at a considerable angle, that agent, when it came in contact with the rock, was deflected from its E.S.E. normal course to a direction of due south, being a deflection of 22°. In the railway cutting, where the slope of the rock was greater, and therefore more obstructive, the striating

agent was changed from its E.S.E. normal course to a direction of E.N.E., being a deflection of 30° or more. At Stirling Castle rock, in consequence of the rock dipping due west, the striating agent was changed from its E.S.E. course to a direction of due south, being a deflection of 22°. So also by the Drylaw boulder the striating agent was not merely deflected, but made to flow past in two separate streams, each of which differed by several degrees from the normal direction.

Now I feel sure that no glacier, even of moderate dimensions, would have been deflected in its normal course by such obstructions. It would have gone straight over these rock surfaces in conformity with the general movement of the whole body of ice; and certainly when it came against the Drylaw boulder, a block weighing less than two tons, instead of being divided by it into two separate streams, the glacier would have forced the boulder out of its way altogether.

On the other hand, a sea-current would be far more likely to be deflected by such obstructions; and if ice was floating in it of such form and thickness as to reach and plough through the sea-bottom, the mud and gravel there might be pushed forward in such a way as to smooth and striate submarine rocks, whether horizontal or sloping.

But whilst I advocate this theory of floating ice to account for the phenomena in this particular district, I admit that there are some difficulties with which the theory has to contend. For example, if the rock on North Berwick Law, described by Mr Stevenson, was smoothed and striated by a mass of clay and stones pushed and pressed against it, what has become of this detritus? because the rock now stands at least from 20 to 30 feet above the detritus at its base. The same remark may be made as to the striations on the rocks at Stirling Castle and Abbot's Craig, which are still higher above any detritus now on the plains below these rocks. This difficulty, however, vanishes, when regard is had to the enormous denudation in every part of Scotland, of which there is ample evidence. Moreover, in the case of North Berwick Law, there is the remarkable hollow in the detritus along its base on the north side, to which reference has been made, showing that the detritus there has been scooped out to a considerable extent, and this may have happened after the smoothing and striation of the rock.

2. On Methods in Definite Integrals. By Professor Tait.

(*Abstract.*)

This paper deals with various formulæ of definite integration which are, in general, put into forms in which they enable us with great ease to sum a number of infinite series. As a simple example of such a formula the following may be given :—

$$\int_0^a f'(x)da\int_0^x \frac{\phi'(y)dy}{f(a)-f(y)} = \phi(a)-\phi(0).$$

From this it is easy to deduce innumerable results, of which the annexed are some of the more immediate. They are written just as they are presented by the formula: when different forms are given to f and to ϕ.

$$\int_0^a \frac{dx}{x+1}\log\frac{\log(a+1)}{\log\frac{a+1}{x+1}} = \log(a+1).$$

$$\frac{1}{1-\frac{1}{a}\frac{d}{dp}}\int_0^a \frac{1}{p}(\epsilon^{px}-1)\,dx = \frac{a}{p}(\epsilon^{pa}-1).$$

If

$$\frac{1}{\log\frac{1}{1-\theta}} = \frac{1}{\theta}+A_0+A_1\theta+A_2\theta^2+\ldots\ldots$$

$$\frac{\pi^2}{6} = 1-A_0-\frac{A_1}{2}(1+\tfrac{1}{2})-\frac{A_2}{3}(1+\tfrac{1}{2}+\tfrac{1}{3})-\frac{A_3}{4}(1+\tfrac{1}{2}+\tfrac{1}{3}+\tfrac{1}{4})-\&c.$$

$$=\int_0^a \frac{dx}{x}\log.\frac{a-x}{x}\,.$$

If $1+\frac{1}{2}+\frac{1}{3}+\ldots+\frac{1}{n-1}$ be put in its lowest terms, the numerator is devisable by n, if n be prime.

The sums of infinite series, such as

$$\sum_0^\infty \frac{\epsilon^{-(x+1)b}}{(x^2a^2+1)((x+1)^2a^2+1)} \text{ and } \sum_0^\infty \frac{(x+1)\epsilon^{-(x+1)b}}{(x^2a^2+1)(\overline{x+1}^2a^2+1)}\,.$$

Several of the above results are easily verified by the usual methods; some, however, seem not readily attackable.

Another formula is

$$\int_0^a f(a,x)dx\int_0^x F(x,y)dy = \int_0^a dy\int_y^a f(a,x)F(x,y)dx.$$

3. Measures of certain Radiometer Constants.
By Professor Tait.

4. Further Researches on Minding's Theorem.
By Professor Tait.

5. On the Transmission of Sound by Loose Electrical Contact.
By James Blyth, M.A.

The following Gentlemen were elected Fellows of the Society:—

John Calderwood, F.I.C., Muirhill, West Calder.
John Charles Ogilvie Will, M.D., 12 Union Terrace, Aberdeen.

Monday, 21st July 1879.

DAVID MILNE HOME, LL.D., Vice-President, in the Chair.

MAKDOUGALL-BRISBANE PRIZE.

The Council having awarded the Makdougall-Brisbane Prize, for the biennial period 1876–78, to Professor Geikie, for his Memoir "On the Old Red Sandstone of Western Europe," published in the Society's Transactions 1877–78, which forms one of an important series of contributions by Professor Geikie to the advancement of geological science, the Medal was presented to him by the Chairman, with the following remarks:—

In accordance with what he was told was the practice on such occasions, he would shortly explain, *first*, the purpose for which this particular prize was instituted, and, *second*, the nature of the memoir and work by Professor Geikie for which the prize had been awarded to him.

The purpose of the founder of the prize was to enable the Council, every two years, to mark, by conferring it, its high opinion of any scientific paper or investigation which might come before it.

The Council was of opinion that the memoir by Professor Geikie,

on the Old Red Sandstone formation, which was printed in the last volume of our Transactions, was of sufficient merit to entitle him to the award of the prize, and especially when regard was had to the many other valuable contributions which had been rendered by the author to geological science.

The Old Red Sandstone formation was well known in Scotland, by reason of the many treatises, both popular and scientific, which had been published regarding it, not only by Scotchmen, but by English geologists of reputation, during the last fifty years. But, notwithstanding all that had been done in the way of investigation, the extent of this Formation on the earth's surface was so great, and the variations in its conditions so numerous, that much remained to be done. There was probably no other Formation, known to geologists, which occurred in so many countries, or which presented so many new forms of animal and vegetable life. It occurred in England, Wales, Ireland, Scotland, Norway, Sweden, Russia, India, South America, and Canada. It was so extensively developed in America, that an American geologist, lately writing on the subject, almost made it a matter of national pride, that the formation was more extensive in Canada and the States, than in Europe, and was also richer in fossils. Professor Geikie had intimated his intention of investigating and describing this Formation as it existed, not merely in Scotland, but on the Continent. The memoir lately printed in our Transactions was a commencement of this large undertaking. That memoir was confined to the north of Scotland,—viz., the counties of Moray, Sutherland, Ross, Caithness, Orkney, and Shetland. The boundary of the formation in these parts was indicated by a great belt of shingle, made up from the waste of the Old Silurian rocks, and forming along their northern and eastern flanks a conglomerate rock. The waters which beat on these Silurian rocks, and in which the deposited sediment ultimately became Old Red Sandstone strata, are believed by Professor Geikie to have been lacustrine,—a view originally suggested by the late Dr John Fleming, and adopted by Mr Godwin Austen and other eminent geologists,—judging by the nature of the plants and fish found in the Scotch strata, none of which were considered marine. On this principle, Professor Geikie has applied to the northern district the term Lake Orcadie. The

next memoir, and for which already materials have been largely obtained, will describe the formation as it occurs in the middle district of Scotland, under the title of Lake Caledonia; and the third district, comprehending the south of Scotland and the north of England, will be described under the title of Lake Cheviot.

It was not necessary for him (the Chairman) to refer to Professor Geikie's identification and classification of the rocks composing the strata in the Scotch northern counties, or the different fossils found in them. His object was merely to point out the nature and importance of the investigation entered on by Professor Geikie, and on account of which this prize had been awarded. He had read with the utmost interest the exposition given in the memoir, indicating, as it did, a large amount not only of personal labour on the part of the author, but of great knowledge and ability. He hoped that this prize would be accepted by Professor Geikie as a heartfelt acknowledgment and testimony by the Council of the eminent services he had rendered and is rendering to science by this work. He was sure also that the Professor would be pleased to have his name added to the roll of eminent men of science who had gained this prize in former years, at the head of which roll stands Sir Roderick Murchison, whom Professor Geikie frequently alluded to in his memoir as his "old chief," and whom they all respected not merely for his great geological discoveries, but for the substantial benefits conferred by him on our Edinburgh University, by founding in it that Chair of Geology which Professor Geikie so ably fills.

The Chairman, having then invited Professor Geikie to come forward, placed in his hands the Gold Medal and a bank cheque, adding, as from himself, that it gave him peculiar pleasure to have been called on to perform this duty.

The following Communications were read:—

1. The Solar Spectrum in 1877-8; with some Idea of its Probable Temperature of Origination. By Piazzi Smyth, Astronomer Royal for Scotland.

(*Abstract.*)

This solar spectrum contains measures of about 2000 fixed lines, or fully a third more than are represented in Ångström's worthily

celebrated Normal Solar Spectrum Map, which is taken as the standard reference for "place." The observations were made in Lisbon during the summers of 1877–8, with apparatus prepared by the author; who aimed at including everything visible, from the extreme red to the extreme violet ends of the spectrum, so far as that is amenable to the human eye after transmission through glass.

The author also strove to include only true solar lines, with the least possible admission of such as are produced by the earth's atmosphere. Finally, he compares his so far purified solar result against upwards of 5000 observations of laboratory workers in chemistry, after reducing them to the same spectrum scale; and finds indications that the solar chemical elements are incandescent in a probably far higher temperature than—probably twice as high as—anything yet attained by man.

2. On another Method of Preparing Methylamine. By R. Milner Morrison, D.Sc.

On a former occasion I drew attention to methyl sulphate of ammonium as a suitable material for the preparation of methylamine by heating it with quicklime. There is another and better method of arriving at the same result, the extreme simplicity of which was probably the cause of its being overlooked at the time.

A glance at the formula of methyl sulphate of ammonium shows that it is an isomer of acid sulphate of methylamine, viz. :—

$$CNH_7SO_4.$$
$$\begin{matrix}CH_3\\NH_4\end{matrix}SO_4.$$

Methyl sulphate of ammonium.

$$CNH_7SO_4.$$
$$\begin{matrix}CH_3NH_3\\H\end{matrix}SO_4.$$

Acid sulphate of methylamine.

Methyl sulphate of ammonium is an unstable salt, decomposable by a moderate amount of heat, while acid sulphate of methylamine is a much more stable body, hence it becomes probable that if the unstable substance be heated the atoms in the molecules of which it is composed will tend to arrange themselves in that order which is most stable at the temperature to which they are subjected, and therefore that in this case acid sulphate of methylamine will be produced.

Such, in fact, is the case. A portion of *dry* methyl sulphate of ammonium was heated by itself in a sealed tube to about 300° C. for about two hours, nearly the whole of the salt being converted into acid sulphate of methylamine.

When the tube, after cooling, was examined, it was found that a very small portion of the salt had undergone a complete decomposition, some carbon being set free. On opening the tube a small quantity of gas was given off, which was inflammable, and smelt somewhat etherial, with a trace of sulphurous acid. The salt had been fused, and had solidified to a crystalline mass, and now possessed a strongly acid reaction.

This salt, distilled with caustic potash, and the evolved gas collected in hydrochloric acid, the solution, evaporated to dryness on the water-bath, gave a hydrochlorate which, on heating with lime, gave off an inflammable gas in abundance, was deliquescent, soluble in alcohol, and when warm possessed the smell of methylamine hydrochlorate.

Several portions of methyl sulphate of ammonium were heated to different temperatures and for different lengths of time, in order to find out the most advantageous method of preparing the substance.

As there appears to be some regularity in the relation between the temperature and time and the amount converted from one salt into the other, I intend making further research in that direction; and for this reason I have for the present contented myself with only a platinum estimation, for the purpose of determining the amount of methylamine hydrochlorate present in the crude mixture of methylamine hydrochlorate and ammonium chloride. For the purpose of this estimation a portion of the crude hydrochlorate, as obtained by evaporating the hydrochloric acid solution to dryness, was dissolved in water and precipitated with chloride of platinum. The double chloride so obtained was washed, dried, and the platinum estimated by ignition.

The following are the percentages of platina found in the double salts obtained from four experiments under varying circumstances :—

(*a*) 25 grammes of methyl sulphate of ammonium were heated to 300° C. for 2 hours.

(*b*) 25 grammes of the salt were heated to 300° C. for 1 hour.

(*c*) 20 grammes „ „ 200° C. for 2 hours.

(*d*) 20 grammes „ „ 200° C. for 1 hour.

Per cent. of Pt.

41·6 in methylamine double salt (calculated).				
42·0 in double salt from *a* (found).				
43·1	„	„	*b*	„
43·43	„	„	*c*	„
43·67	„	„	*d*	„
44·1 in ammonium double salt (calculated).				

These numbers represent a percentage of hydrochlorate of methylamine present in the crude salt of—

in (*a*) 84 per cent.
in (*b*) 40 „
in (*c*) 27 „
in (*d*) 17 „

This is also confirmed by the deliquescence of the crude hydrochlorates, which is in exactly the same order and very much greater in the case of (*a*) than the others.

3. On the Composition of "Reh," an Efflorescence on the Soil of certain Districts of India. By J. Gibson, Ph.D.

The following brief statement concerning "Reh" is chiefly derived from the Report of the Committee on Reh, November 1878:—

Large tracts of country in the north-west of India have from time immemorial been covered with a white alkaline efflorescence, which renders them incapable of supporting any form of vegetable life. These tracts are called "usar"* plains, and the white efflorescence "reh."† The appearance of this reh on the surface is owing to the subsoil water, which is impregnated with sodium salts, being sucked up to the surface by capillary attraction and there evaporated by the fierce heat of the Indian summer sun. The reh is often very irregularly distributed,—bald patches occurring in the midst of cultivation, or cultivated patches surrounded by reh,—and this capricious distribution has rendered a right comprehension of its

* From the Sanscrit, signifying "barren land."
† Hindee word for saltpetre.

mode of production difficult. It seems certain, however, that its appearance depends chiefly on the distance of the water-table from the surface of the ground and upon the nature of the intervening soil.

When reh exists in the soil it is more largely developed on a surface where the water level is nearer the surface; while, on the other hand, a soil of a close texture,—a clay soil, for instance,—may prevent the formation of reh by hindering the upward passage of the water, even where the water-table is comparatively near the surface. Of course anything which affects the rapidity of evaporation must affect the rapidity with which the reh accumulates, so that the cutting down of trees, and thus exposing the surface of the soil to the unmitigated action of the sun's rays, has an injurious effect and tends to promote the formation of the efflorescence. Until lately an equilibrium of reh distribution was established, at all events approximately. The great usar plains which have existed from unknown times did not increase in extent or change their position; but it would seem that by the introduction of the canal-irrigation system this equilibrium has been disturbed. The Western Jumna Canal—which runs from the Jumna, where it leaves the hills, down as far as Delhi—has developed large tracts of reh, land which was formerly cultivated and fruitful being covered with it, and the same process has begun and is going on with alarming rapidity on the Ganges and Eastern Jumna canals in the country between the Jumna and the Ganges. The evil is of great magnitude, and large tracts of fertile land are fast becoming waste and unproductive, and the condition of the people and their cattle is deteriorating in consequence. Two years ago a committee was appointed by Government to discover the cause or causes of the evil, and suggest, if possible, some remedy. As the result of their deliberation, it is established beyond doubt that this new production of reh is chiefly, if not solely, caused by the system of canal irrigation as at present carried out. In the first instance, the level of the salt-impregnated subsoil water has been much raised, so as to be more readily drawn up to the surface by capillary action and there evaporated, leaving the salts it held in solution as a crust on the surface. There seems to be some difference of opinion amongst the members of the committee, as to whether this is chiefly due to percolation from the bottom and sides of the canals, which are at a

higher level than the surrounding land, or to the system of flush irrigation, which is often so wastefully carried out as to swamp the lands watered. Moreover, in many cases the canals and their distributaries have been so carelessly aligned as to interfere seriously with the surface drainage. The canal water, itself containing more or less of these sodium salts in solution, is a new and inexhaustible source of reh, and though the process in this case may be slow, it is sure, ultimately, to result in the appearance of reh and the consequent unproductiveness of the land.

Various remedies for this state of things have been suggested, some of them very desperate, such as an entire remodelling of the canals, or an extensive system of deep drainage, or the substitution of what is called "lift" for "flush" irrigation, which would mean that every drop of water used be lifted from reservoirs and distributed over the land by manual labour. All efforts to reclaim land once infected with reh, by cultivation or otherwise, have proved abortive.

Mr J. Wilson, M.A. Edin., Assistant Settlement Officer, having sent a small sample of reh to Professor Wilson, with the request that it be analysed, the investigation was kindly intrusted to me, and I now beg to lay before the Society the results of my analysis.

Results of Analysis of Sample of Reh.

Moisture		= 2·5
Insoluble inorganic residue*		= 68·1
Soluble in Water.	Na	= 9·5
	Fe	= 0·1
	NH_3	= 0·35
	SiO_2	= 0·35
	SO_4	= 12·1
	CO_2	= 3·6
	Cl	= 1·9
	Organic matter	= 0·7
	Mg	= trace
		99·2

* Organic matter insoluble in water was not estimated.

Percentage Composition of Soluble Portion.

Na	=	32·4
Fe	=	0·5
NH_3	=	1·2
SiO_2	=	1·2
SO_4	=	41·3
CO_2	=	12·3
Cl	=	8·8
Organic matter	=	2·4
Mg	=	trace
		100·1

From these results it will be seen that the portion of this sample soluble in water, which I suppose to be the reh proper, is mainly a mixture of sulphate of soda, carbonate of soda, and common salt, the sulphate being much the most abundant. I hope soon to have an opportunity of analysing some more samples of reh, the results of which analyses I shall communicate to the Society.

4. On Spherical Harmonics. By Professor Tait.

5. Proposed Theory of the Progressive Movement of Barometric Depressions. By Robert Tennent, F.M.S.

This paper is a continuation and a fuller explanation of the previous one, in which it was attempted to show why barometric depressions, or storms, move forward. In our present state of knowledge, exceptional cases in such an investigation are always to be found, and the subject is consequently taken up in a general point of view. It is attempted here to be shown, not how depressions always move, but how, under certain well-known circumstances, they *may* move.

A depression of a small diameter was shown to be found under a comparatively high atmosphere, in which case it would tend to fill up. But when its diameter is great, say of several hundred miles, and underneath the same real atmospheric height, it may then be considered as existing under a comparatively low atmosphere, which

may be represented by the thickness of a sheet of paper spread over an ordinary globe. The difference in the mechanical effects which must then take place are evidently of great importance. In this latter case, the effect of the earth's rotation will be fully introduced, and the inflow of the winds to the low barometric centre will here have to pass over a great extent of resisting surface, the effect of which was shown. Under these circumstances, a depression will not, as in the former case, tend to fill up; it will now tend to open out, and in one particular direction, which is that of progressive movement. It does not move as a rigid aerial cavity forced onwards by high pressure in the rear, as it is by many supposed to do, but not being a rigid aerial cavity, it can only advance, as it sometimes does, at 70 miles an hour, *as a circular atmospheric wave*, by opening out in front, which may be regarded as being lateral and horizontal extension, and by filling up in the rear. It is difficult to conceive how progress can take place in any other way. This mode of advance was shown to take place only on a resisting surface, and not on a frictionless surface, on which depressions could not advance at all; although the universally received opinion is, that a resisting surface retards progressive movement instead of facilitating it. Storms of the usual diameter move in *direct contact* with the surface of the earth, and not over a mass of calm air resting upon it. Query, Can they move through space? Conclusions were arrived at in a former paper on the barometer, that *its rise and fall was greatly due to the passage of the air over a resisting surface;* on a frictionless surface this would be greatly diminished, and consequently much less difference would then be found to exist betwixt high and low-pressure, which causes and accompanies storms; but if this is not to be found, it will then show one of the reasons why they do not move over a frictionless surface, on which they cannot be opened out by the rotation of the earth.

The motive force which causes storms to move, is here supposed to be a central ascending current which carries off the spiral inflowing winds, which in the different segments are not uniform, either as to their direction or their velocity. Movement takes place in the direction in which supply is least copious, where the isobars are widest, and where inflow is most direct, as shown by Rev. W. Clement Ley in the *Scottish Meteorological Magazine*, with, of

course, as above stated, exceptional cases, which may be afterwards explained. This is shown in the diagram of the ascending balloon.

The rise and fall of the thermometer is equal both above and below its mean, but the *extent of the rise and fall of the barometer is much greater below than above its mean.* This was accounted for so far by "lifting" or fictitious pressure, which accompanies southerly winds, which prevail when the barometer is below its mean.

The second part of this paper is intended to show why storms require high pressure to the right of the direction in which they advance. This is represented by a diagram of a flat wheel, which is laid horizontally on the surface of the ground; it circulates round its centre, which also moves forward in one direction. It is in this way that a depression also moves, say, in an easterly direction. Its winds have a circular rotatory movement round its low centre in a direction opposite to that of the hands of a watch. Let their circular rate of speed be at 30 miles per hour, and let the forward movement of the low centre also take place at the same rate of speed. The consequence of this will be that east winds on the north segment will be at rest—calm—and not move over the ground; at the same time they must necessarily form a segment of the circular rotation round the low centre. If thus at rest, they must cause a collapse, and a termination of the circular rotation of the depression. But they do not do so. To account for this, these east winds may be regarded as being *space* winds, and as such in this way their circular rotation may be maintained. As space winds they actually move, though not over the surface by which their speed is estimated, and hence they may be *said to blow when they do not blow.* West winds on the south segment, having their velocity regarded as being made comparable with the mode in which east winds blow, when they are supposed to be at rest, may be said *to blow more rapidly than they really do blow*, because their speed is not merely to be represented by their circular rotation round the low centre, but also by the additional speed which they acquire in the direction of the advancing low centre. Under these circumstances, *the velocity of east and west winds are not comparable as estimated by their passage over the surface.* To render them comparatively equal, they must be regarded as being both space winds and earth winds.

East winds consequently pass over a less extent of surface when they are not at rest, because they move in a direction opposite to that of progress, and consequently do not require high pressure to aid them on their segment. West winds, which have greater velocity, and pass over a much greater extent of surface, and in the direction of progress, require high pressure on their segment. It is in this way that the point is accounted for. Storms do not move against high pressure in front, except in those cases in which it is far distant.

6. On the Solution of the Simultaneous Equations:— $ax+by=c$ and $dx+ey=f$, when the Symbols denote Qualities. By Alexander Macfarlane, D.Sc.

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